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Environmental adaptation for accessibility: a global perspective in the field of disability, rehabilitation and inclusion

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Environmental adaptation for accessibility: a global perspective in the field of disability, rehabilitation and inclusion

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Editorial: Environmental adaptation for accessibility: a global perspective in the field of disability, rehabilitation and inclusion

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Editorial on the Research Topic
Environmental adaptation for accessibility: a global perspective in the field of disability, rehabilitation and inclusion

Accessibility within the built environment is a critical and primary concern in urban planning and design (1, 2). Public spaces can only be deemed successful if they provide accessibility for all individuals (3). Accessibility must extend to everyone, regardless of physical abilities or financial resources, as it embodies the freedom and ease for individuals to engage and participate in a variety of activities (4–6). Assessing building accessibility and implementing environmental adaptations are essential initial steps in the process of eliminating barriers to accessibility. Such assessments facilitate the identification of accessibility challenges and potential solutions within existing facilities, thereby fulfilling obligations to universal accessibility standards and ultimately making these spaces accessible for persons with disabilities (PWDs) (7–10). However, there remains a notable lack of studies examining the degree and extent of accessibility in public spaces and the adequacy of accommodations provided.

In recognition of World Health Day and the anniversary of the World Health Organization (WHO), Frontiers in Rehabilitation Sciences has launched a series of research topics aimed at highlighting prominent and emerging practices, concerns and developments in rehabilitation all over the world. Given the scarcity of studies focused on environmental adaptations and accessibility, coupled with the journal's commitment to advancing research on emerging rehabilitation practices, we present a special collection dedicated to environmental adaptations and the utilization of assistive technologies to enhance accessibility for a diverse range of end users worldwide. Our objective was to consider the experiences of various end users and the distinct environments in which these practices and technologies are implemented. Additionally, we seek to underscore the latest advancements in environmental adaptations for

accessibility across multiple sectors, including rehabilitation, clinical settings, and social and economic environments.

The eleven articles in this collection speak to six major themes relating to:

1. Advancements in assistive technologies: rehabilitative, clinical, and social environments.
2. End user satisfaction with assistive technologies during rehabilitation.
3. Innovative approaches in the field of environmental adaptations for accessibility in complex public spaces.
4. Advancements in environmental adaptions for accessibility within organizations.
5. Implementation of best practices in the field of assistive technologies during rehabilitation.
6. Emerging trends: environmental adaptations in rehabilitative, clinical, and social environments from a global health perspective.

Through a diverse array of contributions, ranging from original research to systematic reviews, the authors of this special research topic present key findings and advancements in assistive technology from a global perspective, specifically addressing the domain of environmental adaptation for the accessibility of PWDs.

In this special issue, the Ingabire et al. study entitled "*Factors affecting social integration after road traffic orthopaedic injuries in Rwanda*" aimed to identify factors contributing to social integration following road traffic-related orthopedic injuries (RTOI) in Rwanda. This study concluded that the majority of RTOI victims in Rwanda achieved successful reintegration into society; nevertheless, their mobility and community engagement were more significantly impacted compared to other aspects. This study emphasized the importance of early management, effective rehabilitation, and prompt patient discharge from the hospital in facilitating a successful return to everyday life after road traffic-related orthopedic injuries.

The Thériault et al. review article aimed to address the following questions: (1) Which are the current fire evacuation learning strategies used with PWD or seniors? (2) What are the barriers and facilitators for PWD and seniors' during fire evacuation and learning strategies? (3) What is the existing equipment that could be used with PWD seniors? This study found that the current fire evacuation learning strategies currently used can be grouped into three categories: drills; training; promotion of a fire safety plan. Six types of evacuation equipment were found; however, their use has been scarcely documented. They concluded that safety for seniors during fire evacuation is still an important issue to be improved and increasing awareness and creating new practices and tools that consider the strengths and difficulties of seniors seems to be a promising avenue for improving evacuation.

A scoping review on accessibility and inclusion of people with disabilities in international airports by Gotti et al. is considered as the first step of a broader project supported by Canadian accessibility standards, focusing on enhancing inclusive accessibility in Canadian airports. They concluded that services need to be extensively planned, placing a significant burden on passengers. The disability-centric perspective disregards passengers' unique needs and capabilities, leading to a sense of dehumanization. The complexity of airport organizations, shared responsibilities, limited communication, training challenges can deter accessibility initiatives and create discomfort during travel. In this study, they reported that they will be accompanying PWD of various profiles through the various stages of their journey, to gather their perceptions of the travel experience. The results will be then used in conjunction with this study to formulate recommendations and solutions for inclusive accessibility.

Ripat et al. study outlines the creation and standardization of an outdoor environment designed to simulate the real-life conditions and obstacles experienced by manual wheelchair (MWC) users in winter. This project aimed to offer several additional potential benefits, supported by the various stakeholders across the study phases that extend beyond creation of a controlled and safe environment for wheelchair users to develop their winter mobility skills. They have concluded that practicing wheelchair skills in this area may assist wheelchair users in gaining confidence which may ultimately translate to increased participation in the community.

The Corcuff et al. study entitled "*Co-design knowledge mobilization tools for universal accessibility in municipalities*" was conducted to develop knowledge mobilization tools tailored to a specific municipal context in Quebec, Canada, to facilitate the implementation of universal accessibility measures by municipal employees. The co-design process employed in this study was organized into four distinct stages, following the Morales model: (1) Exploration (2) Co-Design (3) Validation (4) Development. The stages one and two highlighted the employees' lack of awareness about universal accessibility issues and their need to have more information and resources about how universal accessibility is encountered in their work. A steering committee co-designed three video vignettes about universal accessibility, the city's action plan and measures included in it. The co-design approach used in this study allowed to observe the non-linear nature of partnership research with an organization as complex as a municipality and showed significant advantages of collaboration between the municipal sector and research.

Derakhshan et al. scoping review was conducted to identify barriers and facilitators to participation in adaptive outdoor physical activity (PA) and identify suggestions for adaptive outdoor PA design. This study identified gaps in knowledge about facilitators and barriers to outdoor adaptive PA and in the design of interventions addressing them. They concluded that future research should focus on the strategies addressing these gaps by involving individuals with mobility disability in designing interventions to gain a better insight into their needs.

Mwaka et al. review study aimed to examine barriers and facilitators of public transport use among people with different types of disabilities during the entire travel chain and to explore perceived self-efficacy and satisfaction related to public transport experiences among PWD. This study showed that people with various forms of disability continue to encounter difficulties in accessing and using public transit throughout the entire travel chain, due to many physical and social barriers despite the adoption and implementation of the Convention on the Rights of

Persons with Disabilities (CRDP). This review identified the physical and social barriers and facilitators that can occur in different links of the travel chain and highlighted issues related to lack of confidence and decreased satisfaction when PWD and older adults are using public transport. The identification of barriers and facilitators to the use of public transport by PWD is an important step that may help policy makers and transport operators around the world to develop and implement interventions to facilitate access, use and inclusion of this mode of transport, as the experiences of PWD when using this mode of transport have an impact on their well-being. The results of this scoping review could lead to a better understanding of the potential barriers and facilitators to the use of public transport by people with various disabilities and how negative or positive experiences throughout the travel may influence their self-efficacy and satisfaction.

In this issue, Kuo et al. article analyzed the risks and benefits that video games may present to individuals with disabilities. Their findings showed that individuals with disabilities are most at risk from excessive video game use, leading to increased aggression, sedentary behavior, and negative impact on academic performance. Identified benefits included promoting physical rehabilitation and psychological well-being, improving cognitive abilities and emotional regulation, and utility in promoting exercises, and managing chronic pain. This article presented a number of strategies and resources to help guide individuals with disabilities, educators, practitioners, and researchers in maximizing the benefits of video games while controlling the risks.

Ramôa et al. study aimed to enhance the accessibility of 2D information for individuals with individuals with blindness or visual impairment (BVI). The rapid advancements in 2D tactile readers and 2D pin-matrix displays hold immense potential for revolutionizing information accessibility for individuals with visual impairments. Based on this study, the Sonoice navigation user interface has emerged as a notable solution, achieving higher levels of efficiency compared to the sonar and voice methods. Their findings highlighted the potential of navigation strategies to enhance the accessibility and usability of tactile graphics for individuals with visual impairments, emphasizing the importance of incorporating such user interfaces in future design and development efforts. They concluded that understanding individual preferences and tailoring the user interface accordingly is essential for optimizing user satisfaction and effectiveness in tactile graphics exploration. Furthermore, as tactile graphics readers and 2D refreshable braille hardware technology continue to grow, it is essential to define optimal user interface standards and expand the capabilities and application domains, further empowering individuals with visual impairments.

Ruiz-Rodrigo et al. study entitled "*experiencing accessibility of historical heritage places with individuals living with visible and invisible disabilities*" was conducted to explore the experiences of people with visible and invisible disabilities when visiting heritage sites considering accessibility issues. The barriers identified by participants in this study were diverse and differ according to the person and the type of disability. However, social and leisure activities were particularly limited, despite the strategies developed by some participants. Participants in the study demonstrated an interest in accessing to heritage places, therefore it seems essential to consider the needs of people with disabilities when developing accessibility solutions, and to seek a balance between preserving heritage and promoting inclusive and equitable access for all.

The "*Enhancing Shared Street Accessibility in Heritage Sites for Individuals with Visual Disabilities: A Canadian Perspective*" study by Lakoud et al. explored how shared streets can be adapted to be more inclusive while respecting the integrity of historical environments. The objective of this study was to explore and propose practical solutions to enhance the accessibility of shared streets for individuals with visual disabilities within heritage sites, with a particular focus on preservation requirements. The study concluded that shared streets can be made more accessible for individuals with visual disabilities by adopting a modular design approach that integrates tactile cues and adaptable urban furniture. These solutions ensure that accessibility and safety can coexist with heritage preservation, promoting inclusivity in public spaces. The research highlights the importance of stakeholder engagement in the design process and offers a replicable framework for improving accessibility in heritage sites globally. However, further field testing is needed to assess the feasibility and acceptance of these solutions within the regulatory constraints of heritage environments.

Final word

To enhance accessibility, environmental adaptations, and the implementation of assistive technologies, it is essential to foster collaboration among end users, healthcare professionals, engineers, architects and policymakers. Interdisciplinary teams must work together to create environments that are accessible to all individuals with disabilities, thereby addressing the needs of this vulnerable population on a global scale. Moreover, conducting qualitative research that incorporates the valuable and meaningful perspectives and insights of PWDs is vital. This approach ensures that the voices of those affected are heard, ultimately leading to more effective and inclusive solutions.

This issue also contributes to another of the fundamental tasks of improving accessibility in the world: raising awareness and educating. The dissemination of knowledge is an invaluable tool in educating us about the great importance of creating accessible spaces for all in the diverse and pluralistic world in which we live.

Author contributions

HS: Conceptualization, Resources, Writing – original draft, Writing – review & editing. EM: Resources, Writing – review & editing. MC: Resources, Writing – review & editing.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Adaptive outdoor physical activities for adults with mobility disability: a scoping review

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Introduction: Outdoor physical activity (PA) contributes to the physical and mental health and well-being of individuals with a mobility impairment. However, individuals are commonly excluded from outdoor PA because of accessibility challenges. No reviews summarizing evidence on factors that facilitate/hinder participation and inclusion of individuals with mobility disabilities in adaptive outdoor PA were identified.. This makes it challenging to establish the key components for implementing inclusive outdoor PA interventions. A scoping review was conducted to identify barriers and facilitators to participation in adaptive outdoor PA and identify suggestions for adaptive outdoor PA design.

Methods: A scoping review of qualitative and quantitative studies was conducted based on the methodological framework of Arksey and O'Malley with modifications by Levac. Barriers and facilitators were categorized into four levels based on a Social Ecological Model (SEM). Suggestions for interventions designed to overcome accessibility issues of outdoor PA were classified based on Universal Design (UD).

Results: Thirty-seven factors regarding barriers and facilitators of outdoor adaptive PA were extracted from 19 studies published between 2002 and 2023. Barriers and facilitators were identified primarily in four levels of the SEM, including intrapersonal, social-environmental, physical-environmental, and policy-related. Eleven design suggestions were identified and categorized according to the seven principles of UD. This study identified gaps in the presented barriers and facilitators and the design suggestions of the included studies, mainly at the social and environmental level, such as a lack of innovation in program delivery and logistics.

Conclusion: This study identified gaps in knowledge about facilitators and barriers to outdoor adaptive PA and in the design of interventions addressing them. Future research should focus on the strategies addressing these gaps by involving individuals with mobility disability in designing interventions to gain a better insight into their needs.

KEYWORDS

outdoor physical activity, adaptive devices, mobility impairment, scoping review, Universal Design (UD), barriers and facilitating factors, participation and inclusion

1 Introduction

Outdoor physical activities (PA) contribute to the physical, mental, and emotional well-being of all individuals (1–3), including individuals with a mobility disability who constitute 10% and 12.1% of adults in Canada and the United States, respectively (4, 5). In addition, previous studies indicate that individuals with disabilities show higher levels of accomplishment and growth while taking part in outdoor activities compared to individuals without disabilities (6). Outdoor PA provides benefits comparable to indoor PA but with additional advantages such as enhanced mood and heightened relaxation (7–9). Outdoor PA can also protect against cardiovascular disease (10). Moreover, individuals are often more motivated to take part in outdoor physical activities than indoor activities because of the inherent appeal of a natural environment (11).

Taking part in PA is a fundamental human right, enshrined in the United Nations Convention on the Rights of Persons with Disabilities (UNCRPD) (12). Six universal principles were introduced by the UNCRPD, including accessibility, autonomy, non-discrimination, equality of opportunities, inclusion, and independence (12). These principles, agreed to by 184 nations, including Canada, entail the obligation to improve existing legislature, integrating them into practice, as well as applying emerging technologies and new design interventions to facilitate the well-being and quality of life of individuals with mobility disabilities to ensure access to outdoor activities.

Despite this emphasis by the United Nations, individuals with disabilities are commonly excluded from outdoor physical activities, primarily because of accessibility challenges (6, 13). Multiple studies identified lists of different facilitators and barriers to participation, such as a lack of awareness of the existence of outdoor recreation programs, limited access to the necessary equipment, and insufficient environmental accessibility (14, 15). Although the information on facilitators and barriers to participation is enlightening in itself, organizations need to apply and use this information as a basis for selecting, designing, and implementing strategies to increase participation in adapted outdoor PA (16).

To promote non-discriminatory design of programs and interventions for adaptive outdoor PA, a variety of different approaches are used, including ability-based design (17), inclusive design (18), barrier-free design (19), and design for all (20). Although these are different concepts, all have the same overarching goal: to provide the most usable and effective opportunities for all who could use the system, regardless of any challenges they may face (21). At this time, no consensus exists on how to formulate the concept of accessibility in diverse areas. However, the concept of Universal Design (UD) (22), which is advocated for in the UNCRPD (12) as a means of addressing accessibility issues in the design of new programs, can be considered as guidance for addressing challenges when designing inclusive outdoor physical activities. As the UNCRPD is part of a larger paradigm shift from understanding disability as "located" in the body of a person towards an understanding of disability as the result of individuals with impairments and their encounters with attitudinal and environmental barriers, UD was proposed as an approach with the potential to empower individuals, dismantle barriers, and create suitable environmental conditions for the social inclusion of everybody, regardless of their abilities (23–25). UD has seven categories or principles that guide the design process, including (1) equitable, (2) flexible, (3) simple and intuitive, (4) perceptible information, (5) tolerance for error, (6) low physical effort, and (7) size and space for approach and use. These principles guide the design process to ensure that the design is useful, adaptable, understandable, effective, safe, comfortable, and spacious for diverse users.

Even though various programs have applied different concepts to design inclusive and adaptive outdoor physical activity interventions, to our knowledge, a systematic analysis of studies and interventions with the goal of synthesizing evidence on adaptive outdoor PA design that facilitates/hinders participation and inclusion has not yet been conducted. The lack of evidence to inform best practices in inclusive and adaptive outdoor physical activity design makes it challenging for program developers to create inclusive outdoor physical activity interventions and programs (16, 26).

For this reason, the present study aimed to review empirical literature about the design of inclusive outdoor physical activity for people with disabilities. The study had three main objectives: To (a) identify facilitators and barriers to participation in adaptive outdoor physical activity, (b) identify design recommendations for adaptive outdoor physical activities, and (c) categorize these recommendations based on the seven UD principles.

1.1 Theoretical framework

Physical activity occurs as a result of a complex interplay of personal and environmental factors (27). The *Social Ecological Model* (SEM) (28) describes the multifaceted network of parameters that affect choices of behavior through interactions between the environment and an individual (29). This model displays both the settings in which the individual participates and those that affect them, even if they don't directly participate (29). Depending on what the particular problem or situation requires, the conceptualization of the SEM can vary between three and five layers (29). A four-layer version of the model proposed by McLeroy and colleagues in 1988 includes the layers of intrapersonal, interpersonal, organizational, and community factors. Central to this model is the individual with their attitude, knowledge, and skills. The other levels are social and physical levels, and they include *interpersonal factors* covering the relationships and interactions that an individual has with other people, such as their family, friends, peers, and co-workers; *organizational factors*, referring to the institutions and organizations that an individual belongs to or interacts with, such as schools, workplaces, or health care facilities, and *community factors*, encompassing the broader social and physical context that an individual lives in, such as their neighborhood, city, or country.

The different layers of the SEM are interconnected and have a dynamic relationship with each other, collectively influencing

individual and collective behaviors and health outcomes (30). Different levels of SEM models interact in the creation of environments and programs that promote physical activity and health behaviors in general. Studying those levels can help to form an understanding of the determinants of participation, as shown by several studies. These studies suggested using customized SEMs to examine participation in sport and recreation across a variety of domains and activities to gain a clearer understanding of participation (29, 31). Bauman et al. (31) used an SEM for outdoor activity. In addition to interpersonal and social factors, their model further elaborates on the role and importance of the natural and built environment, as well as the equipment in the physical environment and policies (31). Furthermore, by removing barriers to involvement, the model may aid the development of programs and policies that strengthen participation (16). This allows the SEM model to combine with other models, such as Social Cognitive Theory (SCT) (32) and the Health Action Process Approach (HAPA) (33) that can be useful for developing adaptive outdoor physical activity interventions that are implemented at one specific level (e.g., policy) to address factors at the intrapersonal as well as interpersonal levels (16). In this context, it will be helpful to divide the social level into two subcategories, namely intrapersonal and institutional/community factors (34). Thus, in this study particular case, the application of such a model to the study of adaptive outdoor activities, a SEM was used with four levels, starting with intrapersonal factors, then social environmental (interpersonal and institutional), physical environmental factors (built environment, natural environment and equipment), and finally policy/regulatory factors (Figure 3A).

2 Methods

This scoping review was conducted following Arksey and O'Malley (35), which was further elaborated by Levac et al. (36). We followed the guidelines on reporting by Peters et al. (37) and the scoping review extension of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA-ScR) guidelines (38, 39) with adaptations from PRISMA 2020 (39) were followed (Figure 1). A multidisciplinary research team (e.g., rehabilitation, kinesiology, psychology) of six co-authors (researchers, graduate and undergraduate students, and one librarian) with experience in conducting literature reviews collaborated on this review.

2.1 Sources and search terms

The research team identified the search terms, including subject headings, that were appropriate for the different

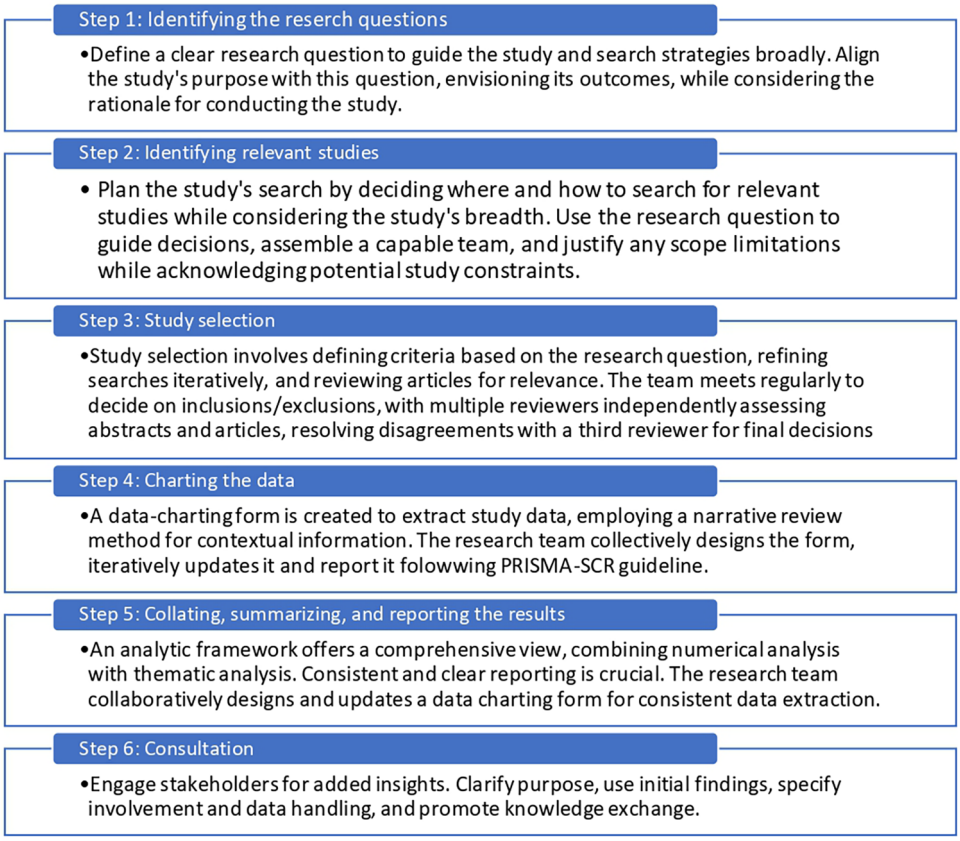

FIGURE 1
Arksey and O'Malley's (35) six stage framework for scoping reviews with Levac (36) recommendations.

databases and keywords with truncations. It then developed a search strategy with the following concepts: (1) Individuals with mobility disability (mobility limitation), (2) Exercise (recreation or physical activity or outdoor physical activity), (3) Adaptive equipment (or sports equipment), (4) Community participation (or social participation). The specific search strategies were based on the Population, Concept, and Context framework (40). Four electronic databases, Medline (Ovid), Embase (OVID), CINAHL (EBSCO), and PsycINFO (EBSCO), were searched without any limitation on the date of publication in April 2023. These searches were regularly updated until September 2023, using the search strings detailed in Table 1. Otherresources were also searches, such as grey literature (Google Scholar and Research Gate), forward and backward citation searches, by hand searches across related journals (Journal of the Association of Computing Machinery-ACM), and conference proceedings. All data sets were uploaded and screened by two researchers using Covidence software (41).

2.2 Selection criteria

The inclusion criteria for selecting resources were as follows: (1) Focused on adult outdoor physical activity or recreation provided to people with mobility disability; (2) Providing information on the perspective(s) of designers/providers/users on program accessibility/usability/inclusivity. All published empirical studies were included if they were published in English, regardless of the methodologies they applied (quantitative, qualitative, or mixed methods). Exclusion criteria were studies (1) focused on hospitals or other health facilities, (2) focused solely on clinical outcome measures, and (3) in languages other than English.

2.3 Selection

The selection process for this study consisted of four steps (36): (1) Identification of all relevant studies in the literature, (2) screening of all studies by applying the inclusion and exclusion criteria to titles and abstracts, (3) determining of the eligibility of the remaining studies by applying selection criteria to the complete papers, and (4) inclusion of relevant studies by re-applying the criteria to the papers in their entirety during data extraction. The Covidence software (41) automatically removed potential duplicates after all relevant databases were searched (Step 1, Identification). In the second, third, and fourth steps (screening, eligibility, and inclusion), studies were independently assessed by two researchers (first author and a research assistant) and completed the review and documented each time the reason for exclusion.

TABLE 1 Search strings and search terms.

1 = Primary Search Term	Exercise/ or walking/ sports/ or bicycling/ or golf/ or hockey/ or mountaineering/ or snow sports/ or skiing/ or sports for persons with disabilities/ or exp water sports/ OR (exercis* or walk* or biking or cycling or golf or hockey or mountaineering or skiing or canoeing or paddling or outdoor activit* or physical activit*).mp. AND disabled persons/ or amputees/ or persons with mental disabilities/ or para-athletes/ mobility limitation/ wheelchairs/ OR [disabl* adj3 (person* or people or individual*)].mp. (para-athlethe* or amputee* or wheelchair*).mp. ((mobility or walk*) adj3 (impar* or difficult* or limit*)).mp.
2 = Secondary Search Term	Adaptive equipment.mp. OR sports equipment/ OR environment.mp.
3 = Tertiary Search Term	Community participation/ OR independent living/ or social participation/ OR [(community or consumer or public) adj3 (involvement or participation or consult* or engage*)].mp.
Final	1 AND (2 OR 3)

2.4 Charting the data

The first author identified the following variables to be extracted from the included studies: (1) the general characteristics of the study (title, author(s), year of publication, country of the study), (2) the type of outdoor activity researched, (3) the target population and the type of their disability, (4) the study design, classified as quantitative (seven designs) or qualitative (five designs) (42, 43), (5) the study aim, (6) the identified barriers and facilitators, and (7) the design recommendations.

The data from the qualitative studies were extracted by reading and re-reading their content, by extracting quotes from the individual studies, and by noting themes and categories. The data from the quantitative studies were extracted into an Excel sheet and then analyzed descriptively. A thematic synthesis approach was used by the first author to code the data. For qualitative studies, the key themes identified in the results section of each article were entered into an Excel database and then manually coded to reflect broader categories. Afterward, these categories were classified according to their conformity with the SEM. The mentioned process conducted by one person (first author). To validate the charting of the data, all of these extracted data were discussed in meetings with co-authors (WCM and WBM).

2.4.1 Charting of factors within the SEM and design principles within UD

The extracted barriers and facilitators, informed by the SEM, are categorized into the following levels: (1) Intrapersonal level, the characteristics of an individual; (2) social environment, including (2a) interpersonal factors; and (2b) institutional or community factors, (3) physical environment, including (3a) natural environment factors, (3b) built environment factors, (3c) adaptive equipment, and (4) policy-regulatory factors. Often, the facilitators were simply the opposite of the barriers. The term "factors" has been utilized to encompass all these conceptualizations to streamline this study's results. The extracted design suggestions are categorized based on their coverage of the seven principles of UD, including: (1) equitable, (2) flexible, (3) simple and intuitive, (4) perceptible information, (5) tolerance for error, (6) low physical effort, and (7) size and space for approach and use. The factors were extracted by one

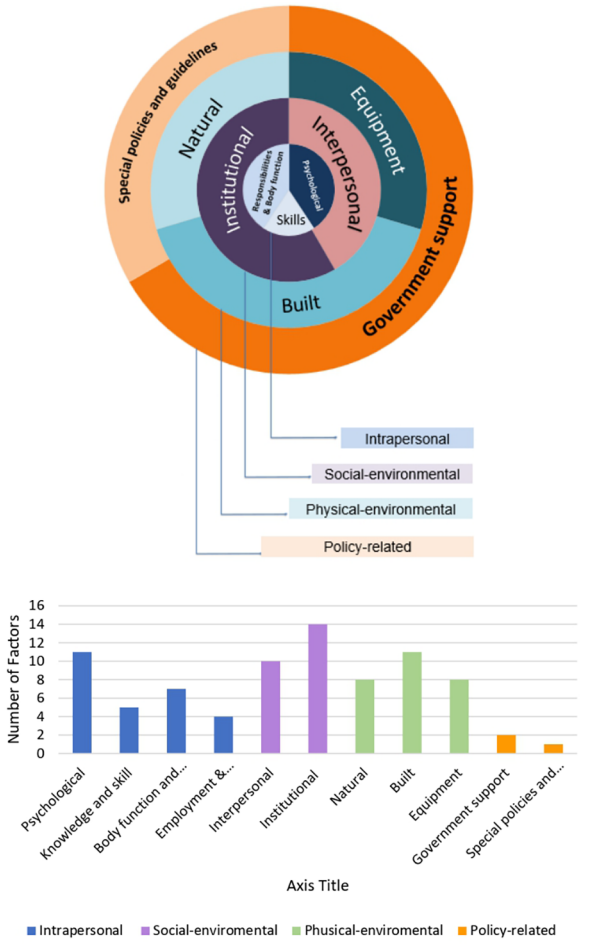

FIGURE 2
PRISMA flow chart.

person, first author, and then validated during meeting with co-authors.

3 Results

After applying the inclusion and exclusion criteria, 20 studies (0.45%, $n = 20/4{,}449$) were included in the study. The PRISMA flow chart is presented in Figure 2. The included studies and their details are shown in Table 2. Most studies were conducted in the US (42.1%; $n = 8$) and Canada (31.6%; $n = 6$), whereas the remaining studies were conducted in Europe (21.1%; $n = 4$ in the UK, Germany, and Denmark) or Australia (5.3%; $n = 1$). Ten (52.6%) of the studies were published in or after 2019. Seventeen studies were published in peer-reviewed journals, and 2 studies were dissertations.

3.1 Key factors related to physical activity

Overall, 37 factors were extracted from the included studies and categorized into 4 levels and 11 sub-levels. The frequency of factors in each category is shown in Figure 3B, and the details of each of its levels and sub-levels are described below.

3.1.1 Intrapersonal level

The factors at this level were categorized into four sub-themes (Table 3): psychological, knowledge and skill, body function and structure, and employment and responsibilities, i.e., family and work responsibilities. The factors most frequently mentioned by studies were *psychological factors* describing the emotions and personality types of individuals, self-perceptions, attitudes, and perceived benefits of outdoor activity. Mainly, character traits of individuals with challenge-seeking personalities, positive attitudes toward outdoor physical activity (e.g., finding friends, enjoying being in nature, and wanting to improve function), and toward themselves (e.g., self-confidence) were identified as facilitators. On the other hand, individuals with risk-averse personalities, negative attitudes toward outdoor physical activity (e.g., anxiety about socializing), fear of being embarrassed, and lack of confidence were more likely to experience barriers to participation in outdoor adapted activities. One study (45), which included recreational and therapeutic programs, indicated that if the participants' goal of joining the outdoor activity matches the program goals, it could act as a facilitator for participation. Nevertheless, it further underlined that enjoying the activity was an essential facilitator for all participants.

In the *body function and structure* subtheme, physical limitations of individuals, such as types and levels of impairment, were mentioned as factors that influence participation. Participants in the included studies stated that as a result of their impairment, they experience fatigue, an inability to know how they would feel on a particular day, and an inability to regulate their body temperature in outdoor spaces properly. Moreover, some individuals mentioned physical health consequences of participation in outdoor activities, such as back pain due to rough and bumpy pathways, as a barrier to their participation. In contrast to this, having knowledge and skills in the handling of assistive devices, such as high wheelchair skills and a familiarity with outdoor sports, helped some individuals enjoy their participation more.

One of the themes that emerged from the included studies was the impact of work and the financial situation of individuals with mobility disabilities on their participation in outdoor adaptive activities. The last subtheme deals with the *employment status and responsibilities* of individuals with mobility disabilities. On the one hand, an individual with a mobility disability who works or has a responsibility to their family mentioned lack of time as a barrier to their participation. On the other hand, low no income and financial instability in general are barriers to participation in an outdoor adaptive activity. These findings suggest that individuals with mobility disabilities have different needs and preferences when it comes to engaging in outdoor adaptive activities and that these factors should be taken into account when designing and implementing such programs.

TABLE 2 Characteristics of included studies.

References	Year of publication	Type of study	Participants	Number	Type of activity/ equipment	Aim(s)
Lawrason et al. (44) CA &USA	2022	Quantitative	Spinal cord injury ambulator	43	Community outdoors and/or indoors	Identify behavior change factors related to LTPA in SCI ambulators.
Merrick et al. (45) CA	2021	Qualitative	Children and adults requiring physical, cognitive, and/or psychosocial supports	26	Adapted paddling programs	Explore the experiences of participants
Alsaleem et al. (46) USA	2020	Qualitative	Individuals with spinal cord injury- Tetraplegic	9	Tetra-Sail	Describe the iterative design process of designing an adaptive sailing program.
Alsaleem et al. (17) USA	2020	Qualitative	Individuals with spinal cord injury- Tetraplegic	17	Tetra-Ski & Tetra-Sail	Explore the experience of individuals using shared-control and ability-based design principles.
Menzies et al. (47) CA	2020	Qualitative-Semi-structured interviews	Participants who need to use a manual wheelchair for at least 4 h a day	15	Various outdoor recreation	Explore experiences and identify the perceived barriers and facilitators
Corazon et al. DK (48)	2019	Qualitative	Individuals with mobility disability	24	Various outdoor recreation (green spaces)	Examine experiences and related constraints
Alsaleem et al. (49) USA	2019	Qualitative	Individuals with spinal cord injury- Tetraplegic	8	Tetra-Ski	Describe the iterative design and field evaluation of Tetra-Ski.
Everett (50) USA	2019	Mixed methods study	Individuals with disability	1,746	Non-motorized boating	Explore the barriers to participation
Mavritsakis et al. (51) CA	2019	Qualitative	Individuals with disabilities-Past and current users of adaptive snow equipment	20	Adaptive snow sports	Explore the experiences and factors that impact participation
Labbe et al. (52) CA	2019	Qualitative	Individuals with disabilities, staff, volunteers	36	Various outdoor recreation	Evaluate the benefits and explore facilitators and barriers to participation
Labbe et al. (6) CA	2019	Qualitative	Sailors with disabilities, staff, and volunteers	38	Adaptive sailing program	Explore the experiences, identify the perceived benefits of participating, and explore facilitators and barriers to participation
James et al. (53) CA	2018	Qualitative	Individuals with disabilities, staff, and volunteers	20	Adaptive hiking program/ TrailRider	Explore the experiences of users and nonusers of the program
Darcy et al. (54) ASTL	2017	Quantitative	Individuals with disabilities	1,046	Various outdoor recreation	Examine the barriers to sport participation
Burns et al. (14) UK	2013	Qualitative	Individuals with disabilities and support assistants	56	Various outdoor recreation	Explore participants' views and experiences of outdoor recreation
Burns et al. (55) UK	2009	Qualitative	Individuals with disabilities	56	Various outdoor recreation (woodland and countryside leisure visits)	Explore participants' experience
Freudenberg et al. (56) GER	2009	Quantitative	Anglers with physical disabilities	775	Recreational fishing	Identify and compare benefits and barriers to participation experienced by anglers with and without disabilities
Goodwin et al. (57) USA	2009	Qualitative	Adults with spinal cord injury	4	Hiking (TrailRider)	Understand the experience of participating
Burns et al. (58) USA	2007	Quantitative	Individuals with disabilities and their household	336	Various outdoor recreation (national forest visits	Examine the perceived barriers of participants in relation to the presence of a person with a disability in one's household.
Williams et al. (13) USA	2004	Quantitative	Individuals with and without mobility disabilities	585	Various outdoor recreation	Describe and compare the outdoor recreation participation patterns of individuals with mobility disabilities with those of individuals without disabilities, and report on the differences between these two groups in terms of constraints to participation
Gransee (59) USA	2002	Qualitative	Women with physical disabilities	19	Various outdoor recreation	Explore constraints and strategies for the participation of women with physical disabilities in outdoor recreation

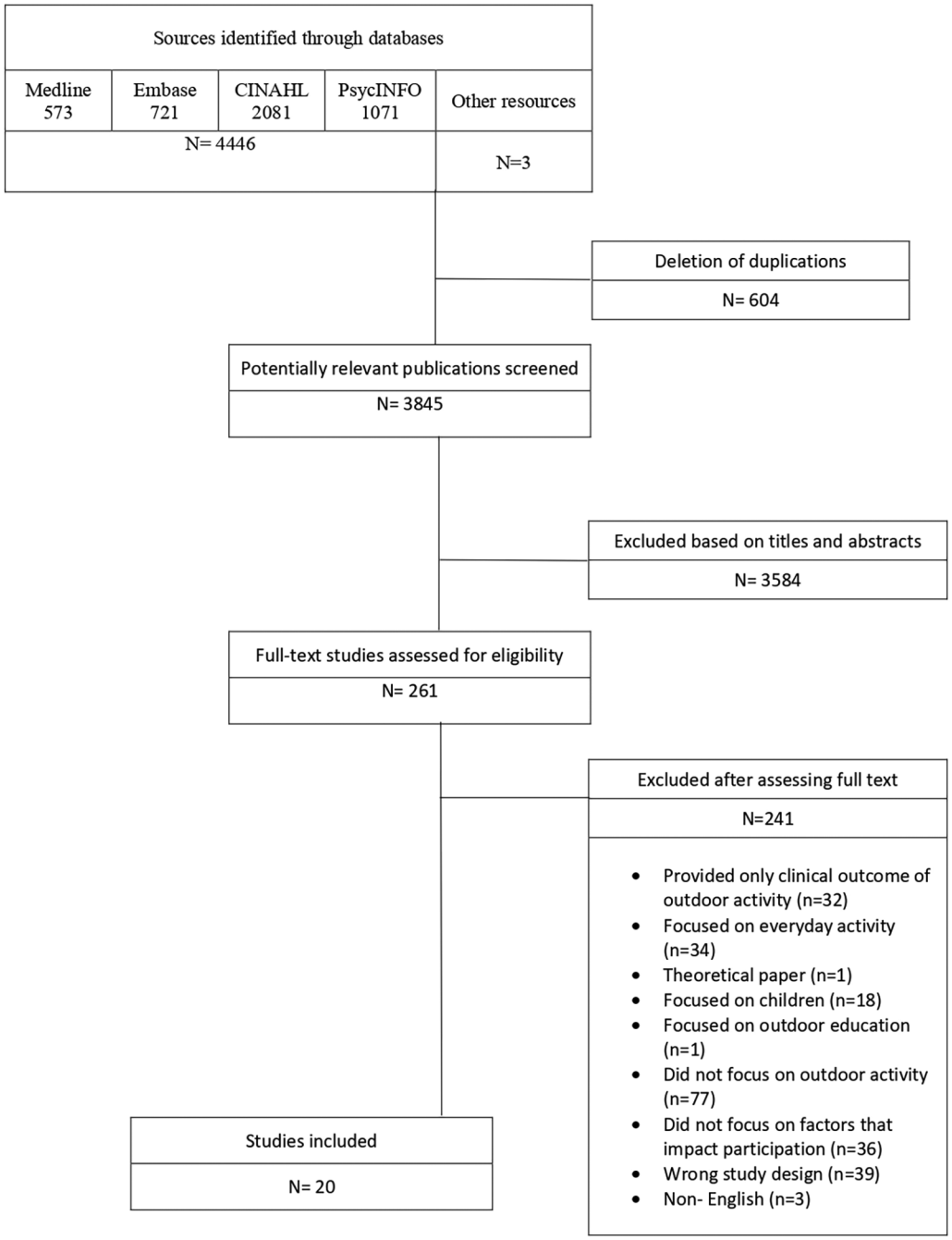

FIGURE 3
(A) The socio-ecological model. (B) Distribution of factors by category.

3.1.2 Social environment level

3.1.2.1 Interpersonal

On the interpersonal sub-level (Table 4), factors were categorized into two sub-themes: social support and attitude. *Social support* can come from families, friends, peers, and other participants of the program. On the one hand, this support can be a form of encouragement to participate, a companionship, and assist them during the program or sports activity, for example, if it is a joint family activity such as skiing. On the other hand, a negative *social attitude*, such as low expectations of the abilities of people with disabilities and stigmatization by onlookers during the program, could be a barrier for individuals with mobility disability.

3.1.2.2 Institutional and community

In this level (Table 4), the factors most frequently mentioned as facilitators in studies were availability, knowledge, competency, and attitude of the volunteers and staff. Another factor that positively affects participation is assessing the needs of

TABLE 3 Intrapersonal factors.

Psychological	Personality (risk aversion vs. challenge seeking)
	Attitudes toward outdoor physical activity
	Self-perceptions
	Congruence between activity/program and personal goals
Knowledge and Skill	Assistive device skills
	Familiarity with outdoor activities
	Awareness of the availability of adaptive programs
Body Function and Structure	Physical capabilities
	Health outcomes of activities
Employment & Responsibilities	Financial capabilities
	Responsibilities and time constraints

individuals with disabilities and gathering sufficient information or insight during program design and implementation. For example, users were eager to participate in customized activities that fit their needs and focused on their strengths. In some programs, they were not satisfied with the activity because they felt it did not meet their desired level of independence (14, 45, 47, 52, 53). An additional factor mentioned in two studies (6, 52) was the importance of a simple and organized booking process and scheduling of the program's procedure.

3.1.3 Physical environmental level

This level consists of factors categorized in the following subthemes: physical (natural and built) environment and adaptive equipment (Table 5).

The *physical environmental* factors that affect the participation of individuals with mobility disability in adaptive outdoor physical activity are part of the *natural* or the *built* environment. The positive effect of blue and green space on physical and mental health is mentioned as a great facilitator for participants returning to a program (45, 47, 51, 58). However, weather conditions (e.g., rain, snow, or cold temperatures) and terrain conditions (such as poor trail conditions and a general steepness) result in a situational impairment that limits the use of adapted programs and presents barriers to their design and development.

TABLE 4 Social Environment factors.

Interpersonal	Social support	Having companions (family, friends, others)
		Social circle's support of outdoor activity
	Social attitudes	Stigma (e.g., being stared at)
		Expectations of the abilities of individuals with disabilities
Institutional	Staff and volunteers	Knowledge and competency of staff and volunteers
		Supportive attitude of staff and volunteers
		Number of available staff and volunteers
		Dissenting opinions of organisers on health and safety aspects
	Program delivery and logistics	Complexity of booking and scheduling
		Organization of daily operation
		Amount of planning and time an activity takes
		Amount of equipment per program
		Cost of program
		Amount of information or insight during designing
		Assessment of PWD's needs
		Extent of the independence provided
		Customization options of an activity to fit the members' needs
		Focus on the members' strengths
		Amount of safety precautions implemented by organizations

TABLE 5 Physical Environment factors.

Natural	Effect of green and blue space
	Weather condition
	Terrain condition
Built	Safety of the environment (e.g., the facilities or paths are shared between program participants and able-bodied individuals)
	Access to necessary infrastructures (e.g., washroom, elevator, etc.)
	Access to the location (e.g., long distance, direct public transportation, pay for parking)
Equipment	Handling of equipment (weight and size)
	Availability of specialized leisure equipment
	Diversity of equipment
	Cost of equipment
	Flexibility of equipment (e.g., seasonal usage)
	Maintenance requirements
	Storage requirements
	Access to local equipment
	Accommodation of various ergonomic needs
	Need for assistance during installation and use

Hosting adaptive physical activities in nature usually leads to a great distance from the homes or workplaces of the participants, and the lack of accessible public transportation to the facilities was frequently cited as a barrier in studies. One study (53) suggested using a transportation system exclusive to individuals with disabilities; however, unreliable arrivals and departures and the possibility that the transportation schedule may not coincide with the time of the outdoor activity is still a barrier to individual participation. Moreover, three studies (6, 14, 60) mentioned a lack of necessary infrastructure at the location of the outdoor activity, such as accessible washrooms or elevators. In one program (14), sharing facilities and pathways with abled-bodied users negatively affected the implementation of the adaptive program and, in some cases, was perceived as risky.

The *adaptive equipment* used in a program was mentioned as a factor in 8 studies (6, 45, 47, 48, 54, 56, 60). Although the present study does not aim to focus on the details of the design of the equipment, the following factors are extracted from included studies. Participants found a program's high diversity and specialized equipment to be a facilitating factor. One study (6) mentioned the importance of regular maintenance of the equipment. In addition, four (6, 45, 48, 60) studies were concerned with the logistics of the equipment, such as the limitations of getting in and out of with a low seat rear-wheel hand cycle; another one mentioned the significance of the equipment's ergonomics, specifically the posture of the user when using the equipment. On two occasions (45, 54), participants wanted to purchase their own equipment, but its high price and the required storage space needed for the

TABLE 6 Policies and regulations factors.

Government support (e.g., financial support)
Special policies and guidelines (e.g., restrictive policies in recreation, demand for special insurance)

equipment, which can only be used during a specific season, was the barrier that prevented them from doing so.

3.1.4 Policies and regulations level

The factors categorized at this level (Table 6) directly relate to policies at the governmental level. Two main factors emerged from the included studies that fall directly under the purview of government policymakers, including government support (mostly financial support) and health and safety regulations and guidelines. Participants of two studies (14, 45) mentioned the importance of safety regulations. When the regulations are restrictive (such as asking for special insurance), it affects the autonomy and perceived risk of people with disabilities in outdoor activities.

3.2 Designing for adaptive outdoor physical activity and UD principles

At this point in this research, both designs implemented by studies and designs recommended by users during qualitative interviews to maximize the inclusion and accessibility of adaptive outdoor physical activity were identified. The seven principles of UD were used as an analysis tool to map the recommendations.

Nine studies identified design recommendations on the accessibility aspect of adaptive outdoor physical activities. These recommendations are closely aligned with some of the seven UD principles for adaptive outdoor activity design. Autonomy and independence as overarching principles that characterize UD were specifically mentioned in one of the studies (45). Participants suggested adding additional active elements to the equipment to make it more independent. In the following section, the most prevalent suggestions from the 9 studies, grouped into seven principles, will be named and expanded upon.

Principle 1-Equitable Use: Three of the proposed recommendations were on the intrapersonal level, including advertising a program through the local health center to provide equitable knowledge about its existence, and lowering the cost of the program to provide equitable access to low-income individuals. One study (45) suggested designing equipment with the same appearance as equipment of able-bodied users. This design aims to mitigate the interpersonal barriers and stigmatization encountered by users of adaptive equipment during interactions with observers and onlookers. Another recommendation (47) was to rent shared equipment to simultaneously address the barriers of the high cost of adaptive equipment, the need for storage, and its seasonal usage. This would also help ensure that users are not constrained by program schedules and restrictive policies and improve their independence (47).

Principle 2-Flexible Use: Two design suggestions are detailed in this section. Both aimed to improve the flexibility of the adaptive activity by making the equipment more flexible. That is, first (17), to design the equipment in a way that it can be customized and adjusted for all types of mobility disabilities, as recommended in two studies. For example, one of the studies (49) designed a sailboat called the Tetra-Sail, which is a novel sailing system that utilizes a Shared-Control paradigm to combine commands from both a primary user and a skilled adaptive trainer (control collaborator). This study mentioned that a wheelchair system can have a variety of adaptations and customizations, depending on the health condition of its user, many of which should also be included on Tetra-Sail. Their design on the sailboat featured basic elements such as seat adaptability, padded cushions to decrease pressure, straps to keep different body parts in place, holders for drinks and medication, and additional space for any health equipment a user might need (e.g., an electrical ventilator). The second suggestion (51) is to design the equipment in such a way that users have the option to choose their preferred level of autonomy, which will result in them gaining more self-confidence. An example of this suggestion is mentioned in one of the studies (53), which aims to explore the experiences of users participating in an adapted hiking program that utilizes a specialized mobility device called the TrailRider. The TrailRider is a one-wheeled chair equipped with handles and brakes, enabling individuals with disabilities to access natural environments. It is employed in adapted hiking programs worldwide, where volunteers aid riders in navigating challenging landscapes. Attaching a steering wheel to the TrailRider to turning it into an off-road wheelchair and the Shared-Control design of the Tetra-Sail, are examples of transferring control to the users. Creating multiple levels of control allowed for a variation in difficulty and made it possible to design a challenge that matches the skill level of the participants, which is an important factor in the enjoyment and performance of physical activities.

Principle 3-Simple and Intuitive: Two suggestions were brought forward for making an outdoor activity simple and intuitive, where volunteers played an important role. The first suggestion (45) was to use a peer mentor with a mobility disability and the experience to accompany staff or volunteers during the program. An individual with the same disability can understand the difficulties that users encounter better and can transfer knowledge and experience to users more effectively. The second suggestion (49) was related to the presence of a knowledgeable volunteer who gives the user feedback on equipment use during and after completing a task. Getting feedback and communicating with staff in general, as mentioned in other studies, will be discussed in detail in the next principle.

Principle 4-Perceptible Information: Effective communication between the user and a trained partner, who gives the user real-time information and assistance based on their performance, is essential. Transparent communication one of the principles of an ability-based design approach and was used in the Shared-Control Tetra-Sail program (46). In this program, a person with a tetraplegic spinal cord injury is coupled with an assistant to

perform the sailing activity. The features and functions of the activity are divided between the individual with a disability (user) and the partner (control partner). For more effective communication between the user and the control partner, the designers added a Bluetooth speaker to provide feedback on the user's sip-and-puff commands. However, ensuring effective communication can be a challenge to some degree in other contexts, such as the Tetra-Ski (49). For example, in this instance, it is possible for the controlling partner to call out short phrases to the participant while skiing, but the participant has limited ability to communicate back to them. To complicate things further, while the control partner is able to see and respond to the general movements of the participants on the joystick, this is not possible when equipment such as a sip-and-puff device is required.

Principle 5-Tolerance for Error: Individuals with a mobility disability are often seen as being "at risk" outdoors. This can be a barrier to their participation, no matter if it is a result of their own fear of being at risk (intrapersonal barrier) or because of societal (interpersonal) and institutional perspectives (environmental barrier). Multiple design strategies were provided by the studies that are included in the present scoping review to minimize the risk of participation of individuals with a mobility disability. A study on Tetra-Ski (49) addressed this issue by sacrificing autonomy in exchange for their safety. The designers limited their customization options to a predefined set of options, as certain user preferences can lead to dangerous situations. The alternative strategy was to shift equipment control back and forth between the trainer and participant to find a safe setting with the right amount of control that worked for both of them. In one study (49), a simulation of the program was conducted prior to the actual program to assess the level of safety for each individual based on the function of each participant. If the participant demonstrated limited function and mastery of the device during the simulation session, the trainer would be in control of the equipment. Generally, having reliable volunteers, constant communication between volunteers and staff members, and a reliable assessment of weather conditions by staff were important strategies that facilitated the creation of a safe environment for activities. In another study (6), the safety of the program was ensured through the use of special equipment, such as using specific materials for a boat to prevent it from sinking, as well as maintaining regular maintenance intervals by assigning a specific employee to be in charge of repairs.

Principle 6-Low Physical Effort: Studies provided five design suggestions to make adaptive outdoor physical activities efficient, comfortable, and low in fatigue. All of them suggested modifications to the equipment, including (1) reworking seats to account for scoliosis, spasticity, and improve trunk control (53), (2) changing the design of hand cycles to be rear-wheeled or high-seated to facilitate mounting and dismounting (53), (3) lighter equipment to provide access to a trail in the woods and a beach (47), (4) adding a removable front wheel to facilitate movement on rough or soft terrain by raising the casters of a wheelchair (47), and (5) providing a basic and advanced option for the equipment to let the user switch between them in case of fatigue (49).

Principle 7-Size and Space for Approach and Use: To guarantee adequate space for individuals with mobility disability, studies suggested the installation of a floating dock to facilitate launching a boat and smaller equipment to make turning and maneuvering on trails easier (6, 53). In terms of the scope of designing equipment, it's worth mentioning that the majority of the studies primarily focused on designing equipment and interventions for specific adaptive activities. Five studies were related to adaptive sailing (6, 17, 46), paddling (45), or fishing (56), three studies focused on snow sports (51) and skiing (49, 56), and only two studies explored adaptive hiking (53, 57), both of which examined the TrailRider design. While there were studies that examined various outdoor activities, they did not provide specific design suggestions for equipment.

4 Discussion

This scoping review of peer-reviewed and non-peer-reviewed studies shows that the factors that impact the participation of individuals with mobility disability in adaptive outdoor physical activity can be categorized, informed by an SEM, as intrapersonal, social environmental, physical environmental, and policy-related. The results of this review suggest that each of these factors can act as a barrier or a facilitator. To improve the participation of individuals with mobility disability in adaptive outdoor physical activities, barriers that exist at multiple levels of the model must be addressed, and facilitators must be maintained or newly established. In the context of the present scoping review, design suggestions to address these barriers were also mapped based on UD. These design suggestions are discussed below, along with the most prominent factors identified by this review and the relevant interventions suited to increase outdoor physical activity participation of individuals with a mobility disability.

4.1 Intrapersonal factors

Intrapersonal factors were the most frequently identified factor that influenced the participation of individuals with a mobility disability. These factors included a large range of aspects, such as attitude, emotion, behavior, and self-perception. Design suggestions aimed to make programs more flexible to (1) give users with a mobility disability the option for more autonomy, which leads to more self-confidence, and (2) provide tailored equipment and a safe environment, which helps to reduce the user's perceived risk of an outdoor activity. However, none of the included studies mentioned applying any behavioral theories to facilitate participation in adapted outdoor physical activity, despite there being evidence in favor of it at the psychological level within behavior change theories and models. For example, the HAPA (52) contains constructs that include concerns about potential behavioral risks (i.e., risk perceptions), self-perceptions (i.e., self-efficacy), attitudes toward outdoor physical activity (i.e., outcome expectations), and strategies for behavior change (i.e.,

action planning). This study encourages combining SEM with different theories of behavior change to explore how psychological factors affect the participation of individuals with a mobility disability in adapted outdoor physical activity and how different designs can facilitate participation.

Factors mentioned in the chapter about *Body Function and Structure* were the second most frequent factors. These factors encompass experiencing fatigue due to their impairments and the physical health consequences of outdoor activities resulting from non-inclusive environments and equipment. By connection the identified limitation with UD principles, Design suggestions with the aim of ensuring a low physical effort (principle 6 of UD) sought to reduce the level of fatigue and secondary health concerns resulting from adaptive outdoor activities. Previous studies on the physical activity of individuals with mobility disabilities mentioned that body function and structure factors could completely prevent participation or affect the types of activities a user can take part in (16). This review agrees with those findings and suggests that the extent of body function also has the potential to limit the user's autonomy. For example, in a shared-control ski program (49) for individuals with tetraplegia, the trainer would take over complete control if the medical staff suggested that an individual is unable to safely control the ski on their own. From this, it follows that the level of the user's body function decides how much control they have over their ski, thus affecting their independence.

To better understand how individuals' independence is impacted, it is essential to examine how studies and participants with mobility impairments define independence. In the majority of studies, dependence is often defined in line with the common-sense understanding of being unable to perform tasks oneself, leading to reliance on others to accomplish some or all desired activities (61), such as transferring or using assistive devices (14, 45, 47, 52, 53). Conversely, independence implies self-reliance, where individuals do not require assistance from others. Despite the absence of explicit measurements for independence in these studies, Burns et al. (14) referenced Oliver's concept of enforced dependency (1993) (61), where he argued that societal and economic structures, rather than impairments themselves, render individuals with mobility impairment dependent on others. Furthermore, he commented on the definition of independence as a complete self-reliance that within a modern industrial society, absolute independence is a concept that doesn't apply to anyone, given our mutual interdependence (61). Hence, the dependence of people with mobility impairment, is not a unique feature which sets them apart as categorically from the rest of the population but rather distinguishes them by different levels of dependency.

When considering the level of dependence, it is important to differentiate between independence and interdependence. The former enables individuals with disabilities to make their own decisions through support systems. However, some researchers challenge the notion of independence as the ultimate accessibility goal. They argue that everyone relies on others to some extent and emphasize that self-sufficiency can harm people, particularly those with disabilities. Instead, the researchers advocate for interdependence to achieve access. For example, one can argue that the shared-ski program is an application of the interdependence frame due to the relationship between user and trainer, adaptive device, and environment to create accessibility and improve quality of life. Independence and interdependence should not be viewed as opposing or incompatible concepts; instead, they complement each other.

Limited time and income were the third most frequently mentioned intrapersonal factors in the reviewed studies that pose barriers to participation (45, 52). This barrier is already identified by many previous studies on the physical activity of individuals with a mobility impairment (16, 47, 52, 62). Designs that attempted to make a program more equitable, for example, by renting shared devices and offering the program at a low price, sought to address the barrier of low income. It is important to emphasize the importance of equitable cost of programs because financial barriers were found on two levels: first, the barrier of low income on the intrapersonal level and, second, the cost of the equipment and the program itself on the environmental level.

4.2 Social environment level

4.2.1 Interpersonal factors

This study identified social support and social attitude factors on the interpersonal level. Although most of the studies mentioned these barriers, only one of them (45) made a suggestion on how to reduce the stigma toward outdoor activity of individuals with a mobility disability by introducing the social-relational model to the discussion. In this model, disability is conceptualized as a result of relationships with other people and structures. This model refers to the negative impact of society on an individual's participation as "social disablism," which could affect individuals on an intrapersonal level through negative attitudes, unsupportive behavior, and insensitive comments. Social disablism can damage self-perception and limit what individuals with disabilities think they can achieve (e.g., participating in sports) and, subsequently, what they are convinced they can become (63). In light of the substantial consequences of social disablism and the identified lack of design suggestions to address this issue, this review recommends researchers, designers, and policymakers prioritize the mitigation of social disablism by considering the identified intrapersonal factors in their work. Examples of this would be to make adaptive device more visible in society by having them offered by more institutions and facilities, thus decreasing the stigma connected to them, and helping individuals with disabilities to improve and increase their social circle.

4.2.2 Institutional factors

The factors mentioned most frequently in the social, environmental, and institutional subtheme were the knowledge and competency of staff and volunteers as well as the insight and knowledge of program designers about user needs, which have often been lacking to date (63). Our study found a gap in design suggestions in the included studies to improve staff's knowledge and competency. This is in line with other studies (16) that

stated that recreation staff and volunteers are frequently criticized for their lack of skills and knowledge in adaptive activities, inclusive environment creation, and guidance or exercise instructions (64, 65). In addition, the knowledge and competency of staff and volunteers could impact other accessibility factors, such as intrapersonal ones (attitude toward outdoor activity and self-perceptions). The lack of attention to this requires policies and educational programs to improve the skills and knowledge of staff and volunteers. For example, organizing regular workshops on disability awareness, communication skills, safety procedures, and adaptive equipment for them will be helpful in tackling the issue (16). Another way of addressing these institutional barriers is by hiring a Certified Therapeutic Recreation Specialist (CTRS) (50). Recreational therapists with the certificate CTRS, certified by the National Council for Therapeutic Recreation Certification (NCTRC), have the required skills, knowledge, and abilities that are essential in recreational therapy. They are capable of implementing accessible programs, satisfying not only the participants but also the organization by demonstrating how important equal access is. Studies showed that larger organizations with greater financial resources and more CTRS among their staff had a better chance of having up-to-date policies, conducting inclusivity training and workshops with their employees, and purchasing adaptive equipment (66).

4.3 Physical environmental level

Our review identified that both the natural and the built environment have the potential to lead to challenges for participants of outdoor recreation with varying abilities (62). This is in line with another study that stated that park visitors and participants are more likely to return for another visit if the facilities, the infrastructure, and the parks in general are well maintained (67). One of the studies (68) mentioned a design suggestion that would allow users with a wheelchair to cross soft ground and sandy beaches; however, this does not relieve the management of parks and public areas of their responsibility to ensure accessibility. They nevertheless play a crucial role in the ability (or lack thereof) of individuals with disabilities to participate in their chosen outdoor recreation activities. Thus, there is a need for standards for an inclusive outdoor environment. Recently, a scoping review showed that there is only a limited number of studies on accessibility standards for nature spaces (69). The results of the scoping review (70) and multiphase study protocols (71) on barriers and facilitators, as well as existing standards of the accessibility of parks that were published, could be helpful for the development of guidelines and best practices to ensure accessibility of nature and the built environment.

4.4 Policy level

The cost of programs and equipment was often cited as a barrier in the included studies, a challenge exacerbated by the fact that individuals with disabilities are typically at the lower end of the socioeconomic spectrum. Governmental support could address this multi-level barrier. It is worth noting that although only two factors are directly related to the policy level, many other factors can also be addressed by acting at this level, by, for example, shaping public policy to improve accessible transportation, volunteer, and staff training, and building an accessible outdoor environment (16). Considering the trend of volunteerism in PA and the need for more training for both volunteers and staff in adaptive physical activity, this study suggests that the government support this process financially and logistically. Furthermore, many volunteers have other obligations, such as full-time jobs or studies, which may limit the time and energy they have at their disposal that is necessary for adaptive PA programs and which leads to barriers to participation of individuals with mobility disability. Also, adaptive outdoor PA might require more support than other PA programs, thus leading them to rely more on volunteers in addition to paid staff. The paid staff in adaptive organizations could be responsible for administrational purposes such as recruiting, training, scheduling, and matching volunteers with individuals with mobility disability based on their skill set. There could be policies to support adaptive PA program to carry out their business in a safe and meaningful way and implementing these policies would have financial implications.

4.5 Mapping designs suggestions using UD

The seven principles of UD, when utilized as an analytical tool with the aim of map design recommendations, can support the design of adaptive outdoor PA. Using UD as an assessment tool should not be limited solely to the end of the design process. Such an approach, which has a tangible impact on users' well-being, may result in additional costs and time for adjustments to accommodate various situations (72). It is essential to assess usability and inclusion throughout the entire project life cycle—before, during, and after construction—by establishing an evaluation framework based on UD principles. For instance, Wu et al. (73) conducted a survey on UD for fitness wearable devices, and reviewed how and when different research efforts examined each principle to develop such devices. The researchers also elucidated how each principle could be incorporated during the design phase of wearable device creation, demonstrating the utility of user-centered approaches in the process (73). This involves alternating iterations and evaluations through methods such as focus groups, interviews, and surveys. Some studies have developed checklists to assess programs. Checklists form the core of the most formal evaluations and serve as the foundation for numerous published studies. Evaluations driven by checklists in UD rely on a set of simplified criteria, typically derived from the seven UD principles. For instance, Kim et al. (74) devised a 27-item measure based on UD principles, assessing user perspectives in sport facilities.

To the best of our knowledge, there isn't an existing evaluation framework based on Universal Design (UD) specifically for assessing outdoor physical activity programs. However, Mosca et al. (72) described their methodology on developing an

evaluation framework for a building throughout various stages of an architectural project, utilizing a multicriteria decision analysis approach. This method was derived from a literature review and workshops involving stakeholders and experts (72). Based on these insights, it's suggested to create an evaluation framework based on UD principles for assessing outdoor physical activity programs. This could involve conducting focus groups and workshops with stakeholders and experts to refine and develop the framework.

Despite that, it is important to note that there are inherent limitations in labeling recommendations, especially those extracted from studies not designed with the conceptual framework of UD. Furthermore, UD strongly emphasizes the promotion and enabling of independence, individualism, and self-reliance, particularly for older individuals or individuals with disabilities (75). Some of the studies indicated that it may not be necessary to design for independence, individuality, or self-reliance. Instead, having a family member, friend, or companion share responsibility during an activity may lead to interconnection and interdependence, which may benefit both parties. This may precipitate a response shift in which people redefine what independence means to them. Nevertheless, presently, UD is still not commonly applied, for which reason there is a lack of innovation, future iterations, and evolutions of UD in relation to adaptive outdoor physical activity. Altogether, the findings from the present scoping review indicate that UD has strong potential; however, additional research is necessary to articulate how UD can ensure inclusion in adaptive outdoor recreation.

To get a better insight into the users' needs, researchers suggested using a Collaborative-participatory design. In this iterative process, the user is positioned at the inside of the design process and acts as an active contributor during each step of the development (76). There are few studies that used this design strategy (77, 78). For example, Slingerland et al. (78) applied participatory action research while designing the Canadian Centre for Mental Health and Sport. They concluded that the design approach gave stakeholders a sense of agency and empowerment in the design and outcome of the project. Thus, this review suggests that future studies use design methods that involve users in the design process and allow them to be active contributors, and then evaluate their effectiveness in the context of adaptive outdoor design.

In the process of designing an adaptive physical activity programs, it's vital to acknowledge that barriers exist across different levels of SEM, with a majority at the institutional level. Future studies should aim to develop programs addressing barriers at various levels (e.g., intrapersonal, environmental, and etc.) within the SEM.

For instance, a program offering rental adaptive equipment can address certain intrapersonal barriers, such as financial limitations and attitudes toward outdoor activities, by providing individuals the opportunity to engage in adaptive outdoor activities with no storage requirements. Additionally, this initiative can address social environment factors by reducing stigma, cutting program costs, and offering greater autonomy in activity selection. Implementing such a design requires training of staff and volunteers for the program and infrastructure development.

For a successful program, it's crucial to consider not only environmental criteria but also institutional aspects, including staff and volunteers. The involvement of professionals, such as physical and occupational therapists, alongside experienced volunteers remain essential. To cultivate a more knowledgeable professional base, integrating relevant coursework or elective programs into their curriculum or providing opportunities for involvement in adapted outdoor programs as staff or volunteers are effective strategies to meet this need.

Additionally, this review underscores the lack of awareness of adaptive equipment, programs, and environments to enable adaptive outdoor PA and shifts attitudes away from impossibility to possibility. In fact, several studies report that rehabilitation centers expose inpatients to the possibilities that influence their awareness (79, 80). When individuals become aware of these opportunities, the likelihood of continued engagement post-discharge may be enhanced.

4.6 Limitation

While this scoping review was conducted vigorously and systematically, there are several limitations to acknowledge. Firstly, the literature included was limited to material published in English; for that reason, findings published in other languages have potentially been overlooked. Secondly, although this scoping review did not restrict the country of the published studies, results originated only from developed countries where urban and rural accessibility infrastructure for individuals with a mobility disability is better developed than in developing countries. Therefore, this review might underrepresent the barriers to participation in adaptive outdoor activity in developing countries. Lastly, the low number of included studies is a recognized limitation.

5 Conclusion

This research categorized factors that impact the participation of individuals with mobility disability, informed by SEM, as interpersonal, social, environmental, physical environmental, and policy-related, and then mapped design suggestions based on the seven principles of UD. This study showed that there are gaps in knowledge about these factors and in the designs addressing them. This study suggests conducting further studies to focus on the strategies addressing the mentioned gaps (such as at the social-environmental level) and to preferably address barriers that exist at multiple levels (such as studies about rental programs of adaptive equipment). At each level, knowledge about the most frequent barriers will be helpful for prioritizing strategies that are best suited for a new design. Finally, This study recommends that designers involve individuals with mobility disability in their design process to gain better insight into their needs.

Author contributions

PD: Conceptualization, Data curation, Formal analysis, Methodology, Visualization, Writing – original draft.

WM: Conceptualization, Writing – review & editing, Project administration, Resources, Supervision, Validation. BM: Conceptualization, Formal analysis, Methodology, Project administration, Supervision, Validation, Visualization, Writing – review & editing. AB: Conceptualization, Data curation, Methodology, Supervision, Validation, Writing – review & editing. DL: Conceptualization, Data curation, Investigation, Methodology, Supervision, Validation, Writing – review & editing. TB: Conceptualization, Validation, Writing – review & editing.

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Barriers and facilitators of public transport use among people with disabilities: a scoping review

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Barriers to public transport use may be experienced differently by people with various types of disabilities (e.g., physical, intellectual, cognitive, sensory). Thus, it is important to identify the variable needs within each element of the travel chain. For example, the unavailability or low volume of auditory announcements in a stop or station or on the public transport vehicle may be a barrier to people with visual disability who rely on hearing the information. Consequently, this could provoke negative emotions and unpleasant experiences, which may not be the case for people with physical disabilities. The primary objective was to describe the barriers and facilitators to using public transport experienced by people with disabilities (PWD). The secondary aim was to explore experiences in terms of self-efficacy and satisfaction, when using public transport among people with disabilities. A scoping review was conducted. The search was performed in MEDLINE, TRANSPORT DATABASE, PsycINFO, EMBASE, and WEB OF SCIENCE from 1995 to 2023. Of 6,820 citations identified, 34 articles were included in the review for extraction. The main physical and social barriers included lack of ramp, long walking distance, long waiting time, unavailability of information at bus stop or station, and drivers' negative attitudes towards PWD. Personal factors that prevented the use of public transport included lack of confidence, and decreased satisfaction with public transport use. Strategies such as providing ramps on public transport vehicles, availability of kneeling buses and courtesy of bus drivers, and travel training were considered as enablers to the use of public transport that can lead the improved self-efficacy and satisfaction. In conclusion, this review identified the physical and social barriers and facilitators in travel chain, and highlighted issues related to lack of confidence or self-efficacy and decreased satisfaction when PWD and older adults are using public transport. Identifying and understanding the barriers and facilitators to the use of public transport by PWD is a milestone that may help policy makers and transport operators around the world to develop and implement interventions enabling access, use and inclusion of this mode of transport, as the experiences of PWD when using this mode of transport have an impact on their well-being.

KEYWORDS

public transport, accessibility, disability, self-efficacy, satisfaction, scoping review

Abbreviations

PWD, people with disabilities; HDM-DCP, human development model-disability creation process, UN-CRDP, United Nation Convention on the Rights of Persons with Disabilities; ADA, American Disability Act.

Introduction

The United Nations Sustainable Develop Goals and the 2030 Agenda for Sustainable Development emphasizes the importance of providing accessible and sustainable transportation systems for all citizens, including the development of public transport, while paying particular attention to the needs of people in vulnerable situations such as people with disabilities (PWD) (1). In this instance, disability refers to the interaction between individuals with a health condition (could be physical or mental) with personal and environmental factors including negative attitudes, inaccessible transportation and public buildings, and limited social support (2). Complementary, universal design is intended to ensure the design and composition of an environment is achieved in such a way that it can be accessed, understood and used to the greatest extent possible by all people, regardless of age, size, or ability (3). Thus, when designing and planning public transport, it is critical to consider accessibility and how to meet the needs of all potential users. Without accessible public transport options, PWD may not be able to easily leave their homes, thus may incur extra expenses to accessing basic community services (4) and are at higher risk of isolation (5). Accessible public transport can facilitate autonomy for PWD, by proving access to community-based services and meaningful social roles, at convenient times. However, to be accessible, PWD must be informed about public transport services, have adequate knowledge, be able to use public transport services, and to be able to afford public transport services (6). Despite the adoption of the United Nation (UN) Convention on the Rights of Persons with Disabilities (UN-CRDP) (7) and efforts to facilitate access to and use of public transport by PWD, many physical and social barriers remain.

Public transport is defined as a system of vehicles, such as buses and trains, that operate at regular times on fixed routes and are used by the public (8). Public transport can play an important role in the travel chain, which suggests that any given travel starts at the origin of the users (e.g., their home) and ends at the final destination (9). In this way, important links of the travel chain include leaving the home to wait for the transport at the stop or station, availability of timetable information, boarding, moving within the transport, disembarking, the use of sidewalks, and the attitudes of drivers and other passengers toward PWD (9).

Barriers and facilitators to the use of public transport may be experienced at any link in the travel chain by PWD. Given the complex and multiple steps required to use public transit, the entire travel chain must be considered to adequately accommodate PWD. It is therefore important to consider leaving how PWD leave the home and get to the stop or station, waiting times, availability of timetable information, boarding, moving within the transport, disembarking, the use of sidewalks, the attitudes of drivers and other passengers towards PWD (10). If there are missing links, experiences with public transport use will likely be less than satisfactory. Various barriers and facilitators can affect self-efficacy and satisfaction with public transport use among PWD, and thus willingness to use public transport (11).

Self-efficacy, defined as belief in one's ability to perform a specific task (12), is considered the most important predictor of travel behavior change (13). Self-efficacy is influenced by factors including past experiences or accomplishments and emotional reactions (12–15). Past accomplishments that are interpreted as the result of a skill developed in the past (16) have been found to be the most influential in influencing self-efficacy (15). Emotional reaction can improve or reduce self-efficacy. Thus, positive experiences with public transport use may generate positive emotions that can enhance feelings of personal efficacy toward public transport use. Conversely, negative experiences can induce negative emotional reactions such as anxiety and doubt, which in turn may impact self-efficacy for using public transport. Therefore, low self-efficacy may be a barrier for public transport use (13).

In two systematic reviews, Risser et al. (17) and Unsworth et al. (18) described public transport accessibility for people with cognitive and mobility impairments respectively. Barriers identified in the selected studies included lack of assistive devices and trained personnel to assist with orientation, problems related to orientation and navigation, uneven pavement, lack of curb-cuts, stairs, narrow doorways, high placement of controls for pedestrian lights and elevators, poor design of street signs, information placed out of reach/sight, inappropriate spaces for wheeled mobility devices, lengthy wait times, and inadequate shelters. However, these studies did not include other types of disabilities, such as visual, hearing, autism, mental/intellectual disabilities, findings cannot be generalized to all PWD.

Given that barriers to public transport use may be perceived and experienced differently by people with various types of disabilities (e.g., physical, intellectual, cognitive, sensory), it is important to identify the variable needs within each element of the travel chain. For example, the unavailability or low volume of auditory announcements in a stop or station or on the public transport vehicle may be a barrier to people with visual disability who rely on hearing the information. Consequently, this could provoke negative emotions and unpleasant experiences, which may not be the case for people with physical disabilities. Similarly, a person with a physical disability who uses a manual wheelchair may have difficulty boarding and the bus in the absence of a ramp, yet a person with a hearing disability may not experience the lack of ramps as a barrier.

Satisfying experiences tend to increase intrinsic motivation, which increases the likelihood to continue a given behavior. Consequently, experiencing satisfaction [i.e., intrinsic positive consequence emerging from a behavior that fulfills the expectations of an individual (19)] during a given activity increases the likelihood for sustained behavior change (13). The most relevant features of the transportation system, such as trip duration, accessibility, fare, network connectivity, information, comfort, safety, and kindness of employees, may influence user satisfaction. Satisfaction with travel can have a significantly positive effect on the frequency of public transport use (20). Indeed, the more satisfied public transit users are with their travel experience, the more they tend to use public transport for their work commute (20).

To respond the gap in the existing literature, this study first aims to examine barriers and facilitators to the use of the public transport (buses, trains, tramway, ferries) by people with different types of disabilities during the entire travel chain. Secondly, this study aims to explore perceived self-efficacy and satisfaction related to public transport experiences among PWD.

Method

We conducted a scoping review to examine the extent of research activity related to the barriers and facilitators experienced by PWD, and their perceived feelings of self-efficacy and satisfaction when using public transportation. The methodology and results were reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA) checklist (21). Arksey and O'Malley's methodological framework guided the review through five stages: (1) identifying the research question; (2) identifying relevant studies; (3) study selection; (4) charting the data; and (5) collating, summarizing, and reporting the results (22). The literature search was conducted in 5 relevant databases including MEDLINE, TRANSPORT DATABASE, PsycINFO (from Ovid platform), Embase, and Web of Science from January 1995 to July 2022, and update was made in May 2023. Studies meeting the eligibility criteria presented in Table 1 were included in this review for date extraction. The results are will be described according to the Human Development Model-Disability Creation Process (HDM-DCP) conceptual framework (23) with respect to the research questions, and the aims of this scoping review. The HDM-DCP conceptual framework addresses disability situations that can arise when personal and environmental factors restrict life habits, thus reducing social participation. It includes personal (e.g., disability) and environmental (e.g., physical, or social barriers/facilitators) factors, and life habits (e.g., the public transport use to go to work). Full details on the development of the methodology, and registration are provided in a published protocol of this scoping review (24).

TABLE 1 Inclusion and exclusion criteria.

Article type	
Inclusion criteria	Exclusion criteria
• Original peer-reviewed manuscript • Guideline report • Concerned with public transport (bus, train, tramway, ferry) accessibility or barriers/facilitators or confidence and satisfaction with public transport for people with disabilities including older people • Published from January 1995 to July 2022 • Published in English or French	• Article for which the full text is not available • Article focuses on the use of technology while using public transport system • Article generally discuss universal design or transportation • Validation study of measurement tools assessing public transport accessibility or travel confidence or travel satisfaction for people with disabilities • Study not involving fixed route public transport (e.g., adapted school bus for students with disabilities, paratransit) • Protocol on public transport accessibility for PWD

Results

As shown the PRIMSA flowchart (Figure 1), a total of 6,816 citations were retrieved in the databases targeted by our research performed in July 2022 ($n = 6,399$) with the search updated in May 2023 ($n = 417$). Four additional references were also hand-selected from the references lists of two systematic reviews (17, 18) for initial screening. After removing duplicates, 5,276 titles and abstracts were screened, and 65 full-text articles were reviewed. Finally, 34 studies met inclusion and exclusion criteria for data extraction.

The age of participants in the 34 selected studies ranged from 12 to 77 years old, and most of them had physical, visual, auditory, intellectual, and mental disabilities, and speech conditions. Of these studies, 19 focused exclusively on PWD, 10 involved older adults, 3 focused on PWD and healthy people, and 2 involved PWD and older adults (Supplementary Table S2). With regards to infrastructure or fixed-route transit mode used, 12 studies focused only on buses, 7 on buses and trains, 3 on buses and rails, 1 on bus and bus stop, 1 on metro stations, and 9 studies combined several modes of public transport including boats, buses, trains, trams, light rails, subway, planes, streetcars, online taxi, private car, and motorcycle (Supplementary Table S2).

Regarding the study design of included studies, Seventeen studies (25–41) used a qualitative cross-sectional design, six (11, 42–46) used quantitative cross-sectional design, three (47–49) were cross-sectional mixed methods, two (50, 51) were longitudinal pre-post quantitative studies, two (52, 53) used an explanatory descriptive approach, one (54) used a longitudinal mixed method, another one (55) used multimethod approach, and two (17, 18) were systematic reviews (Supplementary Table S2). In terms of barriers or facilitators that influenced public transport use, eighteen studies (11, 17, 18, 25–27, 29, 33, 36–38, 40, 43, 46, 48–50, 54) reported both physical and social barriers and facilitators (e.g., lack of ramp or concerns with ramp angle and deployment, lack of training of drivers and other systems users on the needs of PWD, resulting in lack of respect, free pass, lower floor buses, mobility training for people with visual impairment and PWD/age-awareness training for bus drivers), two (31, 55) reported physical barriers (e.g., winter, ice, snow) and personal factors (e.g., fear of injury, lack of knowledge, or self-efficacy), two (11, 35) described only physical barriers, four (30, 39, 42, 45) reported physical and social barriers and facilitators along with influencing personal factors (e.g., fear of being harassed inside the crowded buses, lack of knowledge of the public transport system), six (29, 33, 45, 46, 52, 53) described user satisfaction only, and one (51) described self-efficacy (Supplementary Table S2). Specific details of all barriers, facilitators and influencing factors are presented in Supplementary Table S2.

Several barriers and facilitators, and perceptions in terms of self-efficacy and satisfaction when using public transport among

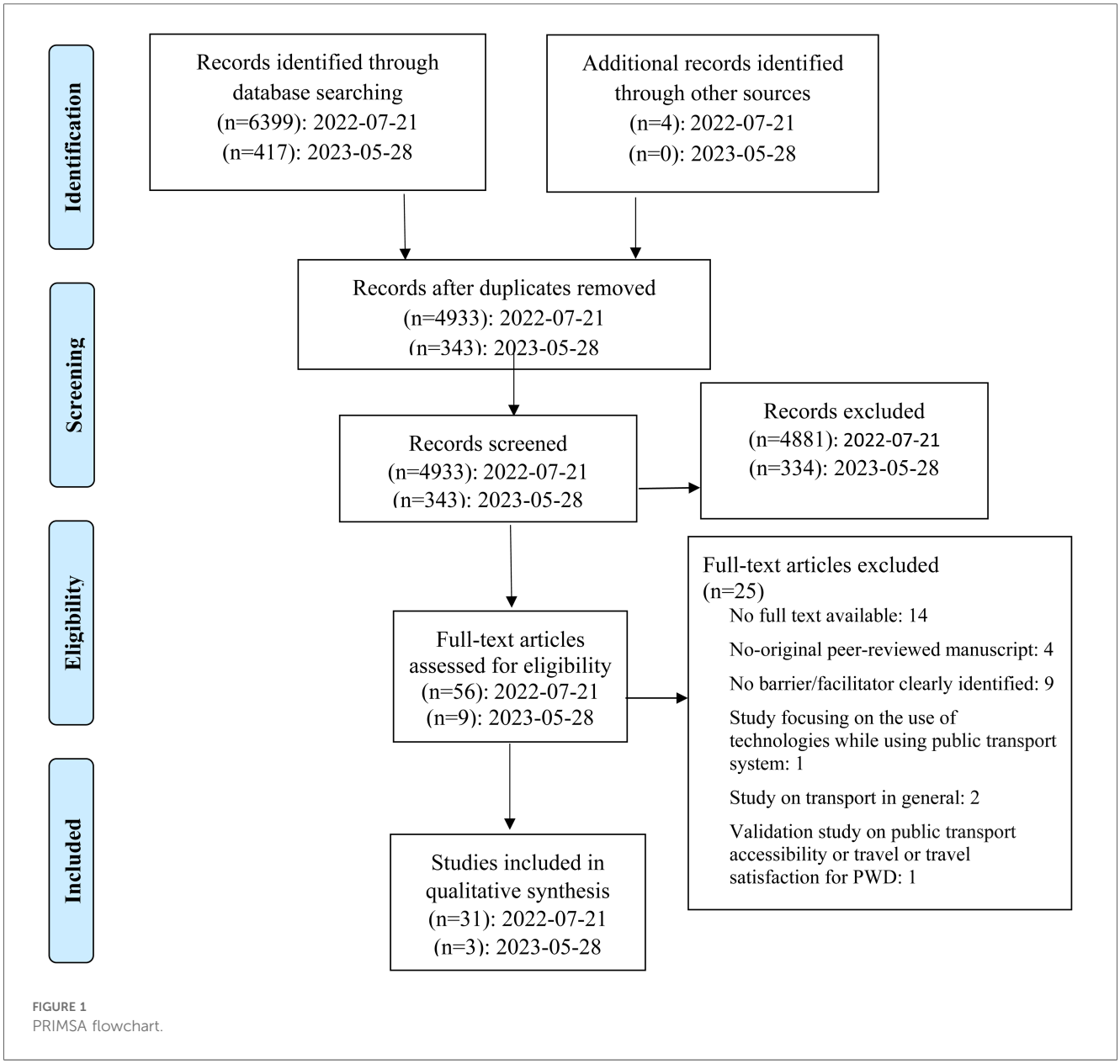

FIGURE 1
PRIMSA flowchart.

PWD were described in Supplementary Table S2. The overview of results of this review was organized according to various links of the travel chain, describing the presence of physical and social barriers and facilitators, as well as personal factors including self-efficacy and satisfaction, and the HDM-DCP conceptual framework.

Travelling to or from the public transport stop or station

Fifteen studies (16–18, 26, 28, 32, 33, 36, 38–40, 44, 47, 50, 54) reported physical barriers faced by PWD in getting to and from public transit stops or station. These barriers included long walking distance, irregular walking surface, narrow pathways, branches hanging in pathways, small holes, poor design of curb cuts, difference in levels, steep side gradient on pathways, low contrast in surface changes, combined pedestrian and bike lanes, grey posts on pathways, crossing with traffic light but no auditory signal, too short time for walk lights, slippery white lines, traffic from two directions, turnstiles lack sound modules to provide information about remaining balance on travel passes, crossing busy streets, lack of sidewalks, weather conditions (e.g., snow, ice and rain, and wind), darkness and unlighted areas, road work, lack of pavement, and lack of dropped curbs.

Considering the physical barriers that may be encountered during this link of the travel chain, five studies (31, 38, 39, 50, 54) have proposed factors which may facilitate access to the physical environment, such as improved pedestrian infrastructure, touch elements in signals, turnstiles with sound modules to assist people with visual impairments, adapt ticket booths and turnstiles for users of different heights, safer intersections with traffic-calming measures, improved

infrastructures with tactile guidance (e.g., floor tiles with gradient textures), snow removal, and public transport route planning with common destinations located short walking distances from bus stops, and the use of visual or audible cues. No studies identified social barriers when going to or from the public transport stop or station.

Waiting at the stop or station

Fourteen studies (18, 28, 30, 36–40, 42, 43, 46, 47, 49, 54) have documented physical barriers experiences while waiting at the stop or station. These issues included unavailable information in terminal or bus stop, drivers not stopping to let people board the bus, platform design and lack of signage, signage quite high and far, signage to bright with glare, high levels of noise, lack of visual announcements on the train, narrow bus stops, grass on bus stop, no weather protection or shelters, no seats or inadequate seats (too high, too low, without back rests), back of the seat slopes backwards, many buses stop at the same bus stop, lack of timetable, small text on timetables, poor visibility on monitors, wrong information, difficult to interpret information, information table too far away, no information about routes in service, no information provided in braille, presence of stairs in railway stations, insufficient lighting in stations, unclean bus-stops and train stations and frequently occupied by people begging, broken elevators or escalators, and long wait times. Indeed, of thirty-one studies reviewed, three reported that long waiting times at bus stops were a barrier to the use of public transport by PWD (18, 30, 47).

The following facilitators to improve access to bus stops or stations have also been identified: touch elements in signals, turnstiles with sound modules for people with visual disabilities, ensuring seating places at bus stops for older adults, making electronic display information of bus arrival/bus delay available, installation of guiding blocks in the railway stations, stairs, and move level surfaces (38–40, 50). One study identified identification of bus numbers as a specific personal factor for people with sight loss (27).

Boarding and getting of the public transport

Nine studies (18, 26, 29, 38, 42, 43, 46, 48, 54) focused on physical barriers related to ramps, including lack of ramp, inoperable ramps, steep slope for ramp use, and ramp deployment angle (≥9.5°). These barriers were experienced especially by wheelchair users. Concerning the deployment of the ramp, American Disability Act (ADA) proposes a maximum allowable ramp slope of 9.5°. Six studies (18, 26, 36, 37, 39, 43) identified the presence of steps at the vehicle entrance as barrier occurring when PWD are boarding or getting off the public transport. Social barriers included false claims of inoperable lifts or ramps made by drivers to avoid letting a PWD board, stress generated by social expectation to be quick as healthy persons, some bus drivers that do not deploy ramps, others do not kneel the buses for unknown reasons were reported in five studies (26, 36, 38, 43, 54). Furthermore, four studies (18, 30, 42, 50) explored factors facilitating access to public transport, including providing ramps on public transport vehicles, availability of kneeling buses and courtesy of bus drivers to lower the bus floor to facilitate boarding (34).

Within the public transport vehicle

Ten studies (18, 25, 26, 29, 30, 37, 38, 40, 47, 54) focused on the physical barriers within the public transport vehicles. These barriers included lack of space or less space for accessible seating, seats sloped backwards, seats without back rests, bus doors swung out, makes stops at unmarked bus stops, all seats occupied, no handrails at seats, narrow spaces between seats, narrow spaces to the seat in front, standing on a bus while it is in motion, wrong information on bus stop information, lack of space for circulation, lack of reliable audible announcements on trains and buses, alert buttons too high, unavailability of seatbelts to secure wheelchair users in place, seats too low, inadequate amount and indication of priority seats. Four other studies attempted to understand the components of the enabling physical environment encountered by PWD on public transport (17, 30, 34, 37, 42). Physical enablers included more space at PWD seats, and grab rails priority seating for older adults, making visual and availability of auditory announcements in the buses, lower pull-cords to call stops, reliable information during the trip.

Ten other studies (29, 33, 36–38, 40, 41, 43, 46, 54) identified social barriers such as less assistance by staff, barriers closely relate to problems with fare cost, lack of respect and buses drivers' behavior causes sudden brakes and acceleration causing discomfort to users, drivers not calling out stops, concerns related to timing and safety, reliability concerns, difficulty to access and exit because of crowdedness, drivers not calling out stops, greater service animal issues for people with loss of sight, unwanted physical assistance and verbal and sexual assault, lack of education of other passengers about health concerns that PWD can have, judgmental and reductive comments made by young passengers towards PWD, safety problems, lack of training of drivers and other systems users on the needs of PWD, drivers stop vehicles far from the platform or bus stop, conflict between wheelchair user and parents with buggies onboard the bus, lack of knowledge for staff on the use of ramp access and other needs of PWD, lack of courtesy from drivers, lack of confidence in the staff (11, 18, 25, 29, 30, 37–42, 44, 46, 54). Eight studies (18, 30, 36–39, 46), reported negative attitudes of buses drivers without specifying the type. Other rare research (29, 36, 49) investigated social enablers such as improved behavior at doors for passenger entrance and exit, reducing bus and train occupancy levels, and adaptation and enforcement of use of preferential spaces, friendly and courteous bus drivers; social interaction by meeting new people on the bus, discounted senior or PWD fares. The resolution of these social problems occurring within public transport requires the involvement of transport service providers

and government authorities. Transport service providers should train and educate drivers about their behaviour towards PWD. Government authorities should consider the fact that PWD and older people generally have low incomes and therefore provide subsidies or exemptions from certain charges (e.g., taxes) to transport service providers so that they, in turn, can commit to providing an affordable preferential fare. This can help make public transport not only accessible, but also inclusive and usable.

Other issues related to public transport use

Twelve studies (18, 27, 31, 35, 38–40, 42–44, 51, 55) reported personal factors such as other issues related to the use of public transport, including inability to navigate public system, lack of confidence in the use of public transport, lack of knowledge of public transport network, and fear of injury related to public transport.

Discussion

This review examined barriers and facilitators encountered by PWD and highlighted their perceived experiences in terms of self-efficacy and satisfaction from 1992 to 2023. Being able to travel by public transport modes such as bus, train, air or ship is an expression of autonomy and facilitates social interactions (42). However, PWD are likely to often encounter difficulties using public transport in their daily lives due to widespread physical and social barriers. Bezyak et al. (43) argued that, despite removal of many physical barriers within fixed-route systems, significant barriers to overall access of public transit systems are still present. This is all the more obvious as the results of this review show that 85.3% ($n = 29$) of the identified studies which pointed out real and perceived barriers of transit-related use and the resulting feeling of dissatisfaction were conducted after 2006, corresponding to the year of adoption of the UN-CRPD [5]. This implies that, despite efforts in terms of legislation, development and implementation of access measures, many physical and social barriers to accessing and using public transport remain and prevent PWD from carrying out many of their life habits activities.

Our study has highlighted the physical barriers that PWD and older adults experienced when travelling to and from stops or stations. These barriers included long walking distance, irregular walking surface, narrow pathways, etc. Travelling to or from stops or stations can be influenced by the characteristics of the built environment, such as the condition of roads and sidewalks, safety, lighting, and the distance between home or another benchmark (e.g., school or market) and the stop. This Particularly regarding walking distance between a benchmark and a stop, UN habitat considers that access to public transport is considered appropriate when a stop is accessible within a walkable distance along the street network of 500 m from a reference point such as a home, school, workplace, market, etc. to a low-capacity public transport system (e.g., bus, Bus Rapid Transit) and 1 km to a high-capacity system (e.g., rail, metro, ferry) (56). Walking distance has been shown to be an important predictor of the frequency of public transport use (44, 57). It is the most important factor to consider when travelling to or from stop or station for at least two reasons: walking is the primary access mode for trips from home to public transit and walking distance has a significant impact on public transport use (57). And this seems all the more plausible given that of the fifteen studies that have reported on the physical barriers that occur when walking to or from a bus stop/station, eight (26, 28, 32, 33, 36, 44, 47, 50) have identified walking distance as a barrier to using public transport. Travelling to or from stop/station must be understood as an integral part of the travel chain, during which barriers may emerge and limit access to and use of public transit by PWD. Government authorities responsible for managing the city should implement measures to make the pedestrian environment accessible to PWD while reducing the home-stop/station walking distance in line with the UN-Habitat recommendations (56). Consistent with findings from Unsworth et al. (18), no studies identified social barriers when going to or from the public transport stop or station. Further research could be carried out to identify the social barriers likely to occur in this link of the travel chain and which may limit the use of public transit by PWD.

Another link in the travel chain where barriers such as the unavailability of travel information, drivers not stopping to let people board the bus, platform design and lack of signage, signage quite high and far, long waiting times, etc. have been identified is waiting at the stop or station. Of the fourteen studies that had identified barriers in this link, three (18, 30, 47) pointed out the long waiting time. Waiting time at a stop/station has been shown to be the temporal component of the travel to which passengers are most sensitive (58). Even a small increase in this time can significantly affect confidence and push them towards other modes of transport (59). UN-Habitat recommends that public transport should have no more of 30 min average waiting time during peak hours (from 5 am to 9 pm) to assess the frequency of the service (56). The responsibility for reducing barriers at bus stops or stations is shared between government authorities and public transport service providers. For example, government authorities are responsible for making bus stops or stations accessible, while the responsibility for reducing waiting times and improving access to information at bus stops lies with public transport service providers. Given we identified no study that has documented the social barriers at public transport stops or stations, research exploring social barriers and facilitators, including personal factors, is needed to guide government authorities and public transport service providers in how tin how to best respond to the public transport needs of PWD.

Nine (18, 26, 29, 38, 42, 43, 46, 48, 54) of the thirty-four studies included studies highlighted the physical barriers associated with ramp issues, and specifically concerned, for example lack ramp, inoperable ramps, steep slope for ramp use, and ramp deployment angle exceeding 9.5°, with as often associated social barriers such as claims inoperable lifts or ramps made by drivers to avoid letting a PWD board, bus drivers that do not deploy ramps or do not kneel the bus for unknown reasons (22–24, 34, 41). Concerning the deployment of the ramp, American

Disability Act (ADA) proposes a maximum allowable ramp slope of 9.5°. Transport operators must ensure that ramp design and deployment features comply with ADA recommendations. Lenker et al. assert that the accessibility of access ramps is affected by their slope, which is often described by a ratio, a:b, indicating a rise of a inches for every b inches in run (60). On this basis, the ADA is recommending that ramps shall have the least slope practicable and shall not exceed 1:4 when deployed to ground level. If the height of the vehicle floor from which the ramp is deployed is 3 in or less above a 6-in curb, a maximum slope of 1:4 is permitted; if the height of the vehicle floor from which the ramp is deployed is 6 in or less, but greater than 3 in, above a 6-in curb, a maximum slope of 1:6 is permitted; if the height of the vehicle floor from which the ramp is deployed is 9 in or less, but greater than 6 in, above a 6-in curb, a maximum slope of 1:8 is permitted; if the height of the vehicle floor from which the ramp is deployed is greater than 9 in above a 6-in curb, a slope of 1:12 shall be achieved (61). This implies that it's not enough just to equip public transport vehicles with suitable ramps; drivers also need to know how to use them, so that they are not perceived by PWD as another source of difficulties preventing them from using this mode of transport. Furthermore, six studies (18, 26, 36, 37, 39, 43) underlined the presence of steps at the entrée of the public transport. PWD are considering steps as walls preventing them from using public transport. Transport operators are called upon to remove these steps to make public transport accessible and usable for this category of the population, which represents around 15% of the world's population.

This review also identified the barriers encountered inside the vehicle. These barriers include physical barriers such as lack of space or less space for accessible seating, seats sloped backwards, seats without back rests, bus doors swung out, makes stops at unmarked bus stops, all seats occupied, narrow spaces to the seat in front, lack of space for circulation, lack of reliable audible announcements on trains and buses, etc. Other barriers concerned social aspects included less assistance by staff, barriers closely relate to problems with fare cost, lack of respect and buses drivers' behavior causes sudden brakes and acceleration causing discomfort to users, drivers not calling out stops, verbal and sexual assault, lack of education of other passengers about health concerns of PWD. These barriers, like the others mentioned above, can have a negative impact on the quality of life and well-being of PWD, by contributing to limit their social inclusion and participation. It is the transport operator's responsibility to address these barriers within the public transport vehicle. The transport operators should have to ensure that all seats reserved for PWD are well adapted, with adequate space to facilitate handling and movement by technical aids. The transport operator is also responsible for making passengers and drivers aware of their attitudes towards PWD and the older adults. Six studies.

Beyond theses physical and social barriers, this study also underlined some personal factors which can limit access and use of public transport among PWD. These included lack of confidence or self-efficacy in the use of public transit (31, 36, 40, 51), decreased satisfaction (29, 45, 46), lack of knowledge of the public transit system (24, 32, 49), and fear of transit-related injuries (31, 35, 39), with special mention for the first two personal factors. Considered as the belief in one's ability to perform a specific task, self-efficacy has been shown to be the most important determinant of behavior change (13). Its reduction regarding public transport can be improved by travel training. Studies on travel training in the use of public transport for PWD and older adults show that such travel training helps them to improve their self-efficacy and knowledge in public transport system, and therefore to overcome fear of the use of public transit (51) and have a satisfactory travel experience. Rehabilitation professionals have a critical role to play in the process of developing training programs and learning how to use public transport for PWD, especially those with lack knowledge and low self-efficacy in their ability to use public transport.

Satisfaction with public transport is often associated with the quality of service provided by the transport operator. That said, if public transport is not accessible due to physical and social barriers, this can lead to a bitter and regrettable experience for PWD, and consequently affect their willingness to use this mode of transport. Conversely, an accessible public transport system can lead to a positive and satisfying experience that can improve the frequency of the use of this mode of transportation to fulfill life habits. The scientific literature argues that the more satisfied people are with their travel experience, the more they tend to use public transport for their work commute (20). Therefore, transport operators are called upon to improve the quality of the services they provide to PWD to promote their inclusion and social participation.

Implications for rehabilitation

- Barriers and facilitators to public transport may be experienced differently by people with disabilities depending on their individual situation of disability (e.g., physical, intellectual, cognitive, visual, or hearing disability).
- Best-practices in public transport may be targeted towards transport providers and policy makers to make public transport accessible, usable, and inclusive for people with all types of disabilities.
- Modifications to the environment (e.g., ramps), and interventions (e.g., staff awareness and education, training in the use of public transport) may facilitate accessibility and use of public transport by people with disabilities.
- Improved public transport use may facilitate social inclusion, participation, and well-being for people with disabilities, the ultimate goal of rehabilitation.

Strength and limits

The strength of this study lies in its methodology. Indeed, we developed this review based on Arskey and O'Malley's methodological framework. This methodological framework is widely used in the development of such a literature review.

Moreover, we used a technical support of a librarian with expertise in the development of documentary research strategies applied to rehabilitation to ensure that we retrieved the maximum number of citations related to the topic of this scoping review. Furthermore, the screening of citations and the articles, and the extraction of data were carried out rigorously and independently by two reviewers to control biases related to any possible loss of information, yet relevant. However, this scoping review also has its limitations. First, even if the keywords used in the search strategy were broad, they might not identify all specialized studies in public transport accessibility for PWD despite consulting of librarian in the choice of keywords and the refinement of the search strategies. Moreover, the fact of having considered only English and French as the languages of publication excluded papers.

Conclusion

This study shows that people with various forms of disability continue to encounter difficulties in accessing and using public transit throughout the entire travel chain, due to many physical and social barriers. despite the adoption and implementation of the CRDP. This review identified the physical and social barriers and facilitators that can occur in different links of the travel chain and highlighted issues related to lack of confidence and decreased d satisfaction when PWD and older adults are using public transport. The identification of barriers and facilitators to the use of public transport by PWD is an important step that may help policy makers and transport operators around the world to develop and implement interventions to facilitate access, use and inclusion of this mode of transport, as the experiences of PWD when using this mode of transport have an impact on their well-being. The results of this scoping review could lead to a better understanding of the potential barriers and facilitators to the use of public transport by people with various disabilities and how negative or positive experiences throughout the travel may influence their self-efficacy and satisfaction.

Author contributions

CR: Conceptualization, Formal Analysis, Methodology, Writing – original draft, Writing – review & editing. KB: Conceptualization, Formal Analysis, Funding acquisition, Project administration, Writing – review & editing, Methodology, Supervision. CC: Formal Analysis, Methodology, Writing – review & editing. MG: Formal Analysis, Methodology, Writing – review & editing. FR: Conceptualization, Formal Analysis, Funding acquisition, Methodology, Project administration, Resources, Writing – review & editing, Supervision.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fresc.2023.1336514/full#supplementary-material

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Factors affecting social integration after road traffic orthopaedic injuries in Rwanda

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Background: Road traffic injuries (RTIs) leading to long-term disability present a significant public health challenge, causing immense personal and societal consequences. Every year, 50 million people are hurt, 1.2 million die, 30% are permanently disabled, and 14% cannot return to work due to road traffic accidents. However, in many developing countries, information on the social integration of patients post-RTI remains limited. This study aimed to identify factors contributing to social integration following road traffic-related orthopedic injuries (RTOI) in Rwanda.

Methodology: A multicenter, cross-sectional study included 369 adult Road traffic orthopedic injuries (RTOI) victims from five Rwandan referral hospitals. Participants completed the IMPACT-S Questionnaire between 2 June 2022, and 31 August 2022, two years after the injury. It measured social integration in terms of activities and paricipation. We used logistic regression statistical analysis with a significance level of $p < 0.05$ to estimate odds ratios (OR) and 95% confidence intervals (CI). The Institutional Review Board for Health Sciences and Medicine at the University of Rwanda College of Medicine ethically authorized this study. Participants signed a written consent form before participating in the study. The data was kept private and was used only for this study.

Results: The study's findings indicated that the mean age of RTOI victims was 37.5 ± 11.26 years, with a notable male predominance over females. Of the participants, 5.69% were unable to resume normal life activities. The overall mean score on the IMPACT-S scale was moderate, at 77 ± 17. Specifically, participants achieved an average score of 76 ± 16 for "activities" and a higher average of 84 ± 16 for "participation." Certain factors were associated with poor social integration compared to others, including belonging to the age group above 65 years (OR = 8.25, $p = 0.02$), female sex (OR = 3.26, $p = 0.02$), lack of rehabilitation (OR = 3.82, $p = 0.01$), and length of hospital stay >15 days (OR = 4.44, $p = 0.02$).

Conclusion: The majority of RTOI victims in Rwanda achieved successful reintegration into society; nevertheless, their mobility and community engagement were more significantly impacted compared to other aspects assessed by the IMPACT-S scale. The study emphasized the importance of early management, effective rehabilitation, and prompt patient discharge from the hospital in facilitating a successful return to everyday life after road traffic-related orthopedic injuries.

KEYWORDS

social integration, road traffic orthopaedic injuries, activities and participation, IMPACT-S, rehabilitation

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Background

Long-term disability resulting from Road Traffic Injuries (RTIs) is a pressing public health concern with devastating effects on individuals and significant societal and economic impacts worldwide (1, 2). Annually, around 50 million people suffer injuries and 1.2 million lose their lives due to road traffic accidents, leaving 30% of survivors with permanent disabilities and 14% unable to return to work (3–5). This primarily affects the working-age population in low and middle-income countries (LMICs), creating profound consequences for individuals, society, and the economy (6).

Effective management of injured patients aims to restore their normal functioning, and various biopsychosocial factors influence post-RTI functional outcomes (7, 8). Social integration of patients post-RTI is a key outcome of successful management, and early psychological support and educating family members play vital roles in promoting social reintegration (6, 9, 10). The International Classification of Functioning, Disability, and Health (ICF) defines participation in life as a crucial health outcome, encompassing an individual's involvement in society's usual activities (11).

Social integration, as defined by the ICF, necessitates interventions to facilitate interaction with the environment for optimal performance in an individual's life (12–14). Various instruments, such as the IMPACT-S questionnaire, measure participation and activities following the ICF guidelines (15). However, individuals with disabilities may encounter challenges in acceptance by their families, limited job opportunities, and difficulties in reintegrating into society (16–18). Adequate rehabilitative care is essential for positive functional outcomes and social reintegration, particularly in LMICs (19).

More than 38.5% of RTI victims in Sierra Leone, Rwanda, Nepal, and Uganda suffered disability, with head and extremities injuries being most common (20). Disability after RTIs in poor countries is affected by injury severity and economic variables, notably for victims' families (2). Road traffic disability affect 1.2%–14% of victims in many developing nations, mostly from low-income households (21, 22).

Rwanda, with 13 million inhabitants and Kigali as its capital, is in Sub-Saharan Africa. Congenital, Genocide against Tutsi victims, and other RTIs made for 5% of Rwandan disability in 2022 (23). The Rwanda National Police reported 4661 road accident injuries and 700 fatalities in 2019 among them a half had orthopedic injuries and 35.6% had permanent and 36% could not return to work (24). Poor post-injury care impairs victims' functional and social reintegration, especially in LMICs (25). Rwanda has many RTI victims (20), few rehabilitation facilities, and few rehabilitation professionals at health institutions, which impacts victim outcomes (26).

This study employs the IMPACT-S questionnaire to identify factors contributing to social integration after road traffic orthopedic injuries (RTOI) in Rwanda, aiming to shed light on improving outcomes and addressing the challenges faced by RTOI victims in the country.

Methodology

Study design and study settings

A multi-centre cross-sectional study was undertaken to analyze hospital-based data on road traffic-related orthopaedic injuries (RTOI) that occurred in 2019 and were treated at the five Rwandan referral hospitals. These hospitals are referral and teaching hospitals with emergency, orthopaedic, mental health departments, and rehabilitation services. The study took place from the 2 June 2022 to 31 August 2022, two years after the injuries occurred, at Centre Hospitalier Universitaire de Kigali (CHUK), Rwanda Military Hospital (RMH), and King Faisal Hospital (KFH), all located in Kigali City, but which receive patients from across Rwanda. The other two hospitals are Centre Hospitalier Universitaire (CHUB) in the Southern Province and Ruhengeri Hospital (RH) in the Northern Province.

Study population and sample size

The study population comprised 2019 road traffic injury (RTI) survivors aged 18 and above admitted to the above five hospitals for both upper and lower limbs injuries. According to the records of the above five mentioned hospitals, around 4,600 cases post-RTIs with 1986 orthopaedic injuries were admitted during the selected study period. We used Krejcie and Morgan's formula (27) for sample calculation and random sampling for sample size. The sample size representative of these RTOI victims was 369.

We consulted the hospital records from the emergency departments, outpatients and admission for patients' demographics and contacts, details of the injury pattern, and the length of stay in the hospital. We excluded participants who were not oriented to time and space and could not respond to the questionnaire and patients with injuries other than orthopaedic. Those fulfilling the inclusion criteria of being above 18 years and having an orthopaedic road injury in 2019 were contacted via telephone for their demographic details and requested to come to the hospital for further evaluation.

Psychometric properties of the instruments

Participation and activities (Social integration) were evaluated using IMPACT-S (ICF Measure of Participation and ACTivities), an ICF-based participation tool called Patient Reported Outcome Measures (PROMS). The measure is designed to describe functioning and disability independent of health conditions and guide the participation level of patients with disabilities. This tool consists of 32 items grouped into nine domains (learning and applying knowledge, general tasks and demands, communication, mobility, self-care, domestic life, interpersonal interactions and relationships, major life areas, community, social and civic life). The IMPACT-S also has two sub-total scores for Activities and Participation and one IMPACT-S total score. All summary scores were averaged item scores, converted into 0–100 scales. Higher

IMPACT-S scores reflect better functioning (or less disability), meaning nearly entirely socially reintegrated in life after a road traffic injury.

This tool was validated by Marcel Post et al. 2008, in 197 road traffic survivors (28) with good psychometric properties according to the ICF framework. The IMPACT-S tool has been validated in conditions like carpal tunnel syndrome (29) and many languages, including Turkish (30). Amir Javanmard et al. 2020 compared six instruments used in the participation and activities evaluation for patients with spinal cord injuries and found that the IMPACT-Shas had higher psychometric measures than other instruments (31). The questionnaire was translated from English to Kinyarwanda by two language experts and back to English by two other language experts to address the cultural and linguistic equivalence, and the responses were the same. Also, we sent the questionnaire to experts in orthopaedic and rehabilitation for their opinion on the quality of translation, clarity and suitability for the Rwandan participants.

Procedure

Of the 1986 patients with orthopaedic injuries, we contacted 1,721 on the phone; some had died, or their phones malfunctioned. The severity of the injury was evaluated using the Kampala Trauma Score (KTS), which is classified as mild, moderate and severe. After sampling, participants were invited to the hospital to assess their current status after almost two years post-RTIs. Using the IMPACT-S questionnaire, we measured the patient's overall level of social integration (participation and activities) after road traffic orthopaedic injuries in Rwanda. Participants filled out the questionnaire by considering how much their impairments interfered with their lives in the last 30 days before the interview. They answered on a 4-point response scale from 0 to 3 (Extreme, considerable, some and no limitations), and the research assistants helped the participants to complete the questionnaire if they could not write.

We calculated each IMPACT-S domain's mean and standard deviation (learning and applying knowledge, general tasks and demands, communication, mobility, self-care, domestic life, interpersonal interactions and relationships, major life areas, community, social and civic life). The participant's socioeconomic status (Ubudehe) was collected according to the Rwanda government classification, where category I include impoverished and vulnerable citizens. Category II includes citizens who can afford some form of rented or owned accommodation but are not gainfully employed and can only afford to eat once or twice a day. Category III includes citizens who were gainfully employed or employers of labour. Category IV are citizens who are chief executive officers of big businesses, full-time employees with organisations, industries or companies, government employees, owners of shops or markets and owners of commercial transport vehicles or trucks (32).

The study's primary outcome is social integration (activities and participation). The risk factors include demographic data, the Kampala Trauma Scale, length of hospital stay, and rehabilitation.

Data management and statistical analysis

Data were collected using the questionnaires, entered into a computer by a Google form data entry mode, and analysed using the R Software. We performed a descriptive analysis of the patient-reported outcome measure scale (IMPACT-S). Categorical variables were summarised using frequencies and percentages, continuous variables with means and standard deviations (SD). We used a student's *t*-test to compare continuous variables and the Chi-Square test for nominal (categorical) variables. We utilised multivariate logistic regression to assess associations between risk factors and IMPACT-S score categories. We considered the p-value <0.05 to be statistically significant.

Ethical consideration

We obtained ethical approval to conduct the study from the University of Rwanda, College of Medicine and Health Sciences Institutional Review Board (18/CMHS IRB/2022). The Rwanda National Research Committee operating in the Ministry of Health approved this study (NHRC/2022/PROT/014), and we collaborated with the Rwanda Biomedical Center (5535/RBC/2022) injury department. We obtained local ethical approvals from the five hospitals' ethics committees; CHUK(EC/CHUK/051/2022), CHUB (REC/UTHB/089/2022), RH(313/RRH/DG/2022), KFH(EC/KFH/015/2022), RMH(RMH IRB/027/2022). We obtained written consent from all participants before enrollment into the study, after explaining the purpose of the study, and all data were kept confidential and only used for the purpose of this study.

Results

Demographic characteristics of the participants

Based on the data provided in Table 1, a total of 369 individuals responded to the survey. Among these, 64.5% (238 participants) were recruited from CHUK. The average age of all participants was 37.5 ± 11.26 years, with the majority falling within the age range of 31–50 years. Males constituted the majority at 74.25%. Approximately 41.73% (172) of all participants attended primary school, and 46.34% (171) resided in Kigali city. A significant portion, 41.73% (154), were engaged in business, while 29% (107) were part of the informal sector without fixed employment. The majority of our participants belonged to category III of the socioeconomic class (Ubudehe), comprising 61.52% (227) of individuals. This was followed by category II, which represented 33.06% of the participants. Additionally, 61.52% of the reported injuries were associated with motorcycle-related accidents.

Clinical factors

Table 2 shows that 52.85% (195) of all participants had isolated lower limb injuries, while polytrauma represented 21.14% (78) of

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TABLE 1 Demographic characteristics of the participants.

Factors	*n* (%)
Hospital	
CHUK	238 (64.50)
CHUB	32 (8.67)
RH	29 (7.86)
RMH	30 (8.13)
KFH	40 (10.84)
Age group	Mean = 37.57 (±11.26)
18–30	102 (27.64)
31–45	199 (53.93)
46–65	59 (15.99)
>65	9 (2.44)
Sex	
Male	274 (74.25)
Female	95 (25.75)
Martial status	
Single	87 (23.58)
Married	265 (71.82)
Divorced	8 (2.17)
Other	9 (2.44)
Level of education	
None	28 (7.58)
Primary	172 (41.73)
Secondary	110 (29.81)
University	59 (15.99)
Residence	
Kigali City	171 (46.34)
Secondary cities	94 (25.47)
Other Districts	104 (28.18)
Occupation	
Farmer	31 (8.40)
Business	154 (41.73)
Students	5 (1.36)
Public service	58 (15.72)
Informal sector	107 (29.00)
Retired	14 (3.79)
Socio-economic status (Ubudehe)	
I	20 (5.42)
II	122 (33.06)
III	227 (61.52)

Primary data.

TABLE 2 Clinical factors.

Factors	*n* (%)
Kampala Trauma Score	
Mild	22 (5.96)
Moderate	247 (66.94)
Severe	100 (27.1)
In Hospital Diagnosis	
Upper extremity injuries	48 (13.01)
Lower extremity injuries	195 (52.85)
Both upper and lower extremity injuries	20 (5.42)
Polytrauma	78 (21.14)
Soft tissues injuries	28 (7.59)
Time before management	
≤1 day	182 (49.32)
2–7 days	116 (31.44)
8–14 days	23 (6.23)
15–30 days	30 (8.13)
>30 days	18 (4.88)
Intervention	
Closed reduction + POP	40 (10.84)
Open reduction internal fixation	155 (42.01)
Open reduction external fixation	57 (15.45)
Amputation	12 (3.25)
Other	105 (28.46)
Length of hospital stay	
0–7 days	149 (40.38)
8–14 days	55 (14.91)
15–30 days	71 (19.24)
>30 days	94 (25.47)
Rehabilitation	
Yes	232 (62.87)
No	137 (37.13)
Level of reintegration	
No limitations (None + Some)	348 (94.30)
Limitations (Considarable + Extreme)	21 (5.69)

Primary data.

cases. Half of our participants were managed within one day (49.32%), with a mean treatment duration of 30 days, and 42.01% (155) were treated with Open Reduction and Internal Fixation (ORIF). Regarding hospital stay, about 55.29% (204) were discharged within 14 days, and the mean hospital stay was 30 days. Our findings indicate that 66.84% (246) had a moderate Kampala Trauma Score (KTS). After completing their injury treatment, 37.13% of the participants were unable to undergo rehabilitation, and 5.69% experienced limitations in integrating into Rwandan society.

The IMPACT-S Table 3 provides a complete overview of many situations and the accompanying levels of limitation experienced by people. As an example, a substantial majority of persons have no limitations in the areas of "Purposeful sensory experiences" (92.95%) and "Communicating, receiving" (96.75%). On the other hand, it is important to acknowledge that there are more significant limitations seen in tasks such as "Lifting and carrying objects" (55.01%) and "Recreational and leisure" (49.86%). Multiple categories, such as "Household tasks" and "Community life," suggest that a considerable fraction of adults have notable limitations, with corresponding percentages of 40.11% and 41.46%. The data shown in the table indicates that although a significant number of individuals do not have limitations in different activities, a substantial fraction of the population encounters significant challenges in certain important tasks and relationships.

Table 4 shows that the results obtained from the IMPACT-S summary scores reveal that people have shown diverse experiences throughout several domains of their life. The mean scores obtained for Knowledge ($M = 88.05$, SD = 22.92), Communication ($M = 98.07$, SD = 8.00), and Interpersonal relationships ($M = 95.89$, SD = 12.29) demonstrate strong findings within these particular areas. However, it is important to note that there are significant challenges reported in the areas of

TABLE 3 Item scores of IMPACT-S.

Factors	Extreme limitations (%)	Considerable limitations (%)	Some limitations (%)	No limitations (%)
Purposeful sensory experiences	1.90	1.08	4.07	92.95
Basic learning	8.67	2.17	8.94	80.22
Applying knowledge	13.01	3.52	10.30	73.17
Task execution in quiet circumstances	5.69	1.63	6.78	85.91
Task execution in stressful circumstances	26.56	21.14	14.36	37.94
Communicating, receiving	0.27	0.27	2.71	96.75
Communicating, producing	0.00	0.54	1.63	97.83
Use of communication devices and techniques	0.81	1.63	4.88	92.68
Changing and maintaining body position	12.20	28.46	7.86	51.49
Lifting and carrying objects	55.01	21.68	7.32	15.99
Moving objects using lower extremities	14.63	26.56	10.30	48.51
Fine hand use	2.44	1.08	5.42	91.06
Gross movements of hand and arm	13.55	10.03	5.69	70.73
Walking and moving	17.34	33.60	6.23	42.82
Moving around using transportation	36.59	22.22	7.05	34.15
Washing and dressing	10.30	18.16	22.49	49.05
Caring for body parts and toileting	2.98	14.63	16.53	65.85
Eating, drinking, maintaining good health	1.63	17.89	14.91	65.58
Acquisition of necessities	5.42	16.26	6.23	72.09
Household tasks	21.95	40.11	5.96	31.98
Caring for household objects	12.47	25.75	10.57	51.22
Assisting others	11.11	12.74	11.65	64.50
General interpersonal interactions	0.27	1.63	2.71	95.39
Formal relationships	2.17	1.90	3.52	92.41
Informal and family relationships	2.71	2.17	3.79	91.33
Intimate relationships	1.36	2.44	3.52	92.68
Education, work and employment	5.69	27.91	4.07	62.33
Managing the long-term financial situation	4.61	2.71	8.13	84.55
Community life	21.68	41.46	6.23	30.62
Recreational and leisure	49.86	22.76	7.32	20.05
Religious and spiritual life	3.79	3.25	4.07	88.89
Citizenship	0.54	1.63	3.52	94.31

Primary data.

Mobility (62.27 ± 24.58), Domestic-life (68.59 ± 29.41), and Community life (67.75 ± 20.01). The research participants exhibited a reasonable level of management across all areas, as shown by the mean IMPACT-S score of 77.10 ± 16.72. This highlights the importance of ongoing rehabilitation and support for the victims.

TABLE 4 IMPACT-S summary scores.

Factors	Mean	SD
Knowledge	88.05	22.92
General tasks	72.76	28.71
Communication	98.07	8.00
Mobility	62.27	24.58
Self-care	77.78	26.10
Domestic-life	68.59	29.41
Interpersonal	95.89	12.29
Major life areas	82.61	25.41
Community life	67.75	20.01
Activities total	76.28	17.81
Participation total	84.16	17.62
IMPACT-S total	77.10	16.72

Primary data.

IMPACT-S scored 0 for extreme limitations, 1 for considerable limitations, 2 for some limitations, and 3 for no limitations. The binary score combined extreme and considerable limitations into one category labelled as a limitation (score 1), while the remaining categories were combined and labelled as no limitation (score 0). Poor social integration was associated with the age group >65 years (p-value <0.01) and female sex (p-value = 0.04). Marital status for separated couples (p-value = 0.03), people in the business category (p-value = 0.01), socioeconomic status category III (p-value = 0.04), lack of rehabilitation management (p-value = 0.01), and length of hospital stay (p-value = 0.02) were also identified as factors negatively affecting social integration (Table 5).

Table 6 is about the The multivariate logistic regression study of IMPACT-S and related covariates yields numerous noteworthy conclusions. The model's intercept has an OR of 0.09, which is substantially different from zero with a p-value of less than 0.01. This shows that the social integration restriction probabilities are 0.09 times the reference group odds when all predictors are at their reference levels. Individuals over 65 had a considerably greater

TABLE 5 Univariate model: association between level of limitation and each factor.

Factors		OR	CI	*p*-value
Age group	Reference (18–30)	0.051	0.01–0.11	0.00
	31–45	0.70	0.22–2.44	0.56
	46–65	1.79	0.48–6.72	0.37
	>65	9.7	1.68–50.86	<0.01
Sex	Reference (male)	0.04	0.02–0.07	0.00
	Female	2.50	0.97–6.24	0.04
Marital Status	Reference (Single)	0.03	0.00–0.09	0.00
	Married	1.56	0.49–6.89	0.49
	Divorced	4.00	0.18–36.43	0.25
	Separated	8.00	0.93–56.90	0.03
Occupation	Reference (Farmer)	0.14	0.04–0.37	0.00
	Business	0.13	0.02–0.64	0.01
	Student	1.68	0.07–15.84	0.67
	Public service	0.24	0.03–1.31	0.11
	Unemployed	0.61	0.18–2.42	0.45
	Other	0.51	0.02–3.96	0.57
Socio-economic status	Reference (I)	0.17	0.04–0.52	0.00
	II	0.39	0.10–1.94	0.20
	III	0.23	0.62–1.12	0.04
Rehabilitation	Reference (Yes)	0.03	0.01–0.06	0.00
	No	3.36	1.34–9.17	0.01
Length Hospital Stay	Reference (1–7 days)	0.02	0.00–6.52	0.00
	8–14 days	–	–	0.99
	15–30 days	3.96	1.15–15.58	0.03
	>30 days	3.8	1.21–14.51	0.02

chances (OR = 8.25, $p = 0.02$) of social integration restriction than the reference group (18–30 years old). Women are 3.26 times more likely than men ($p = 0.02$) to have social integration issues.

Rehabilitation status is important because people who did not undertake rehabilitation are 3.82 times more likely to have social integration ($p = 0.01$). Another indicator is hospital stay length. Patients with a hospital stay of 15–30 days and those with a stay longer than 30 days are more likely to have social integration problems, with ORs of 4.44 ($p = 0.02$) and 4.04 ($p = 0.03$), respectively, compared to those with a stay of 0–7 days. Notably, the 8–14 day hospital stay group had similar chances to the reference group ($p = 0.99$). In conclusion, our model shows that older age (>65), female gender, not receiving rehabilitation, and longer hospital stays (15–30 days or >30 days) are substantially linked with social integration problems.

TABLE 6 Multiple logistic regression of the IMPACT-S and associated factors.

Factors		OR	CI	z-value	*p*-value
Intercept		0.09	0.03–0.36	−6.110	<0.01
Age group	18–30	1			
	31–45	0.51	0.15–1.88	−1.042	0.29
	46–65	1.46	0.54–5.99	0.536	0.59
	>65	8.25	1.15–55.56	2.185	0.02
Sex	Male	1			
	Female	3.26	1.14–9.25	2.243	0.02
Rehabilitation	Yes	1			
	No	3.82	1.39–17.39	2.511	0.01
Length Hospital Stay	0–7 days	1			
	8–14 days	0.004	–	−0.012	0.99
	15–30 days	4.44	1.19–18.81	2.172	0.02
	>30 days	4.04	1.15–16.71	2.099	0.03

Discussion

Our study aimed to determine the level of social integration (activities and participation) following road traffic orthopaedic injuries (RTOI) in Rwanda. The findings of our study revealed several significant factors contributing to limitations in social integration after RTIs in Rwanda, including the age group above 65, female sex, lack of rehabilitation, and a hospital stay of more than two weeks.

In 2019, half of the road traffic injuries in Rwanda were limb trauma, consistent with findings from other studies conducted in LMICs (33, 34). Males were more predominant than females, which can be explained by the higher mobility of men and their greater involvement in general activities in Rwanda, a pattern observed in other Sub-Saharan African countries as well (35–37). Globally, road traffic injury victims are typically in the working age group (38–40) with fewer unemployed (41–43) and our study confirmed this finding. The mean age of our participants was 37.5 years, with a predominant representation in the age group of 31–50 years. The results of our study indicate that the majority of the RTI victims were able to integrate back into their daily activities after the accident.

More than half of the participants in our study belonged to socioeconomic class category III, which included individuals who were gainfully employed or even employers themselves. This finding highlights the association between accidents and a high rate of movement among the victims. Motorcycles were identified as the leading cause of accidents, followed by motor vehicles. As of 2021, there were over 100,000 motorcycles in Rwanda, with half of them operating as moto-taxis (44). It is noteworthy that more than half of the victims in our study had lower limb injuries, and a quarter of them experienced polytrauma at the time of injury. This trend aligns with findings from studies conducted in LMICs, where lower limb injuries are commonly observed in road traffic injuries (45, 46). Among the orthopaedic injuries, more than half of the cases required surgical intervention, either through open reduction and internal fixation or external fixation. The average hospital stay for the participants was 30 days. It is important to note that polytrauma patients who required multiple interventions tended to have extended hospital stays.

Our findings showed that half of our participants were managed within one day (49.32%), with a mean of 30 days and 42.01% were treated by Open Reduction and Internal Fixation (ORIF). The majority were discharged within 14 days (40.38%), mean hospital stay was 30 days 246/368 (66.84%) had moderate Kampala Trauma Score (KTS). After injury treatment, 37.13% of the victims could not undergo any rehabilitation management. For our study, 37% of the prescribed rehabilitation was not done after injury management, primarily due to financial issues and the long distance between their homes and the district hospitals. The same findings were observed in other studies from LMICs where access to rehabilitation ranges from 5%–59%, and in many

countries, rehabilitation centres are lacking (47–49). Lack of rehabilitation in post-RTOI has been associated with a low rate of return to work through a significant impact on the activities and participation of the victims, which is the case in our findings. Many researchers have suggested community-based rehabilitation in post-RTI for complete social integration (50–52).

The primary outcome of this study was the evaluation of social integration using the Measure of Participation and Activities Screener (IMPACT-S). The results indicated that participants had higher scores in the category of no limitations for activities such as communication and production, while the lowest scores were observed in the category of lifting and carrying objects, suggesting that participants were more comfortable with communication tasks compared to tasks that required physical strength. Participants who had some limitations in activities and participation performed relatively well in communication and production but faced difficulties with tasks related to washing and dressing. The category of considerable limitations included participants who encountered significant challenges in executing community life activities, struggling with various daily tasks. More than half of the participants experienced extreme limitations when it came to lifting and carrying objects. These findings underscore the impact of road traffic orthopaedic injuries on important aspects of daily life.

The study findings revealed that while participants scored high in terms of social participation, they faced difficulties in performing activities. This can be attributed to the focus of our research on orthopaedic injuries, which predominantly affect the limbs compared to other body systems. These findings align with similar studies conducted in different countries, such as the study by M. Post et al. in 2008, which validated the IMPACT-S tool. Ahmed Nour et al. (2023) conducted a study in Cameroon and found that more than 39% of patients with limb injuries experienced difficulties with activities of daily living (28, 53).These findings emphasize the need to improve rehabilitation services from the early stages of post-road traffic injuries to address the limitations in activities and promote better social integration.

Studies have consistently shown that the IMPACT-S tool is the most effective tool for summarizing all chapters of the International Classification of Functioning, Disability and Health (ICF) when compared to other tools (15, 31). The IMPACT-S tool consists of nine domains and two subtotals.In this study, the overall IMPACT-S mean score was found to be good for the participants, which is consistent with findings reported by other authors who have also used this tool. These authors have explained that the level of activities and participation becomes acceptable after accidents (29, 30).

Among the domains of the IMPACT-S tool, communication had a higher mean score compared to mobility, which had a lower mean across all domains. This can be explained by the high number of lower limb injuries observed in this study, which is consistent with findings from other studies (28, 30). Furthermore, the activity domain had a lower mean for the IMPACT-S subtotal compared to the participation domain. These findings can be attributed to the specific injuries sustained by these patients at the time of the accident.

After calculating the IMPACT-S scores, we analyzed the factors associated with activities and participation using a binary score. In this scoring system, scores 0 and 1 were combined to represent limitations, while scores 2 and 3 were grouped into 1 to indicate no limitations. Several factors were found to be associated with limitations in social integration. These included being above 65 years of age, female sex, being in a separated marital status, belonging to the business category for occupation, and falling into socioeconomic status category III. These findings provide insights into the univariate factors that can help explain the long-term outcomes of victims of road traffic orthopaedic injuries (RTOI) and their ability to return to everyday life.

Among the clinical factors, the lack of rehabilitation management was also found to contribute to limitations in social integration and longer hospital stays. These factors align with findings from other studies that have identified them as predictors of poor participation and activities in post-RTI scenarios in low- and middle-income countries (LMICs) (48, 54).

Social integration following road traffic injuries (RTIs) is a critical health outcome influenced by various factors. Through multiple logistic regression analysis, we have identified the factors that contribute to limitations in social integration among individuals post-accident. Among these factors, the age group above 65 years was found to contribute eight times more to social integration limitations compared to other age groups. Additionally, females were found to contribute three times more to these limitations compared to males. Lack of rehabilitation had a significant impact, contributing nearly four times more to limitations in social integration compared to attending rehabilitation sessions.

Furthermore, the length of hospital stay has been shown in other studies to be a determinant of social integration following RTOI (17, 45). In our study, a hospital stay of more than two weeks contributed four times more to social integration limitations compared to individuals who spent less than two weeks in the hospital. These findings highlight the importance of considering these factors in understanding and addressing limitations in social integration among individuals recovering from RTOI.

This study will serve as a foundation for future research aimed at assessing the quality of life of individuals with long-term disabilities resulting from orthopedic injuries sustained in road traffic accidents. The findings from this study will provide valuable insights for stakeholders in developing policies and interventions to enhance activities and participation after road traffic injuries (RTIs). Social reintegration following Rwandan road traffic accident-related orthopedic injuries requires a comprehensive approach. After RTIs, efficient treatment should prioritize early hospital discharge and a personalized rehabilitation plan. Victims of Road RTOI breaches need financial aid to overcome their problems and get necessary medical care and support. Additionally, reducing road traffic injury disability rates must be prioritized. Rehabilitative programs and community support networks may help resume everyday activities quickly. Comprehensively evaluating these factors may promote social reintegration and quality of life for Rwandans with orthopaedic injuries from road accident occurrences.

Our study has identified several limitations that should be acknowledged. Firstly, there was a two-year gap between the time of injury and the assessment of patient outcomes. This time lapse

may have introduced variability and could affect the generalizability of our findings. Secondly, we relied on secondary data for both the baseline and follow-up measurements, which presented certain challenges. The use of existing data may have led to missing information and limited our ability to obtain a comprehensive understanding of the patients' conditions. Furthermore, the presence of missing information in the recorded data was another limitation that impacted the generalizability of our findings. The incomplete data may have introduced biases and affected the accuracy of our analysis. Additionally, we acknowledge the lack of qualitative data even as we recognize the potential depth that this kind of data may bring in understanding the variables driving social reintegration in our research.

Conclusion

Our study findings indicate that the majority of road traffic orthopedic injury victims in Rwanda are able to reintegrate into society following the accident. However, certain domains such as mobility and community life are more adversely affected than others. We identified several factors that have a negative impact on social integration after road traffic injuries in Rwanda. These factors include older age, being female, lack of rehabilitation, and longer hospital stays. The study highlights the significance of early management, rehabilitation, and timely discharge from the hospital in facilitating the return to everyday life after the accident. These factors play a crucial role in improving social integration outcomes for individuals affected by road traffic orthopedic injuries.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/supplementary material.

Ethics statement

We obtained ethical approval to conduct the study from the University of Rwanda, College of Medicine and Health Sciences Institutional Review Board (18/CMHS IRB/2022). The Rwanda National Research Committee operating in the Ministry of Health approved this study (NHRC/2022/PROT/014), and we collaborated with the Rwanda Biomedical Center (5535/RBC/2022) injury department. We obtained local ethical approvals from the five hospitals' ethics committees; CHUK(EC/CHUK/051/2022), CHUB (REC/UTHB/089/2022), RH(313/RRH/DG/2022), KFH(EC/KFH/015/2022), RMH(RMH IRB/027/2022). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

JAI: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing; AS: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing; CU: Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Writing – original draft, Writing – review & editing; DM: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Writing – original draft, Writing – review & editing; JS: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing; GU: Conceptualization, Data curation, Formal Analysis, Methodology, Supervision, Writing – original draft, Writing – review & editing; DT: Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing, Conceptualization, Data curation.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Current learning strategies in fire evacuation for seniors and people with disabilities in private seniors' residences and long-term care homes: a scoping review

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Current strategies for teaching evacuation methods in private seniors' residences (PSR) and long-term care (LTCH) homes may pose risks to people with disabilities (PWD) and seniors' physical and psychological health. This study aimed to address the following questions: (1) Which are the current fire evacuation learning strategies used with PWD or seniors? (2) What are the barriers and facilitators for PWD and seniors' during fire evacuation and learning strategies in PSR and LTCH? (3) What is the existing equipment that could be used with PWD seniors?. A scoping review of grey and scientific literature was done in six databases and Google scholar. Additional information was found on Québec government websites. This review identified 13 scientific papers and 22 documents. Twenty barriers (personal = 9, environmental = 11), and 14 facilitators (personal = 4, environmental = 10) were extracted. The current fire evacuation learning strategies currently used can be grouped into three categories: drills; training; promotion of a fire safety plan. Six types of evacuation equipment were found; however, their use has been scarcely documented. Safety for seniors during fire evacuation is still an important issue to be improved. Increasing awareness and creating new practices and tools that consider the strengths and difficulties of seniors seems to be a promising avenue for improving evacuation.

KEYWORDS

fire, evacuation, seniors, private seniors' residences, long-term care home

1 Introduction

Fortunately, most people will never be affected by residential fires, however for those who are, these fires can be devastating and even deadly. Residential fires are even more dangerous to human life when vulnerability becomes a common characteristic among people living in the building, such as seniors, i.e., adults over the age of 65. Indeed, in Canada, between 2014 and 2017, 40% of people who died in a residential fire were seniors and they were 2.5× more at risk than adults (1). In the United States, a 2017 study mentions that 32% of the dead during residential fires were seniors, while they represent only 13% of the population (2). Few statistics

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are available in Europe on the number of fire-related deaths, but the European Fire Safety Alliance (2018) (3) mentions that the seniors are among the most vulnerable, along with people with disabilities (PWD). Private seniors' residences (PSR) and long-term care home (LTCH) are very often occupied by people who have difficulty circulating and going down the stairs. Moreover, even within the normal decline in cognition and loss of some senses linked to aging, learning the right things to do in the event of a fire, as well as the evacuation itself, becomes difficult very quickly (4).

On 23 January 2014, at Isle-Verte, Québec, Canada, a seniors' residence burned to the ground, killing 32 people (5). This tragedy shows that seniors are difficult to evacuate during a fire and has also led to new regulations in Québec, such as the mandatory addition of sprinklers. However, additional measures should be put in place to ensure the safety of this population. Indeed, according to Yves Desjardins, president of the Regroupement québécois des résidences privées pour aînés (RQRA) and Cyrille Delâge, coroner on the Isle-Verte fire investigation, the addition of sprinklers alone would not be enough to ensure the safety of residents (6). Optimising the execution of a "structured evacuation", i.e., the individual evacuation of residents in a structured and safe manner, would be the best method to preserve lives (6, 7), but the learning strategies currently used by firefighters is mainly based on evacuation drills (4, 8–11). In 2015, a survey conducted by the RQRA reported that injuries are frequent during these drills and therefore recommended the creation of alternative learning methods (12). Moreover, the drills procedure currently used in PSR and LTCH are not necessarily adapted to their capacity and living environment (4, 11), making it necessary to improve those protocols.

Thus, it is necessary to review what is currently being done in terms of learning strategies for seniors elsewhere, in order to better identify the practices to put in place. In addition, highlighting the barriers and facilitators encountered during fire evacuation and while learning fire evacuation protocols will help to create new learning strategies that consider the disabilities, strength and the realities of seniors and their caregivers. Therefore: (1) Which are the current fire evacuation learning strategies used with PWD or seniors? (2) What are the barriers and facilitators for PWD and seniors' during fire evacuation and learning strategies in PSR and LTCH? (3) What is the existing equipment that could be used with PWD or seniors?

2 Methods

Two scoping reviews have been realised, following the steps of Arksey and O'Malley (13), one with the scientific literature and one with the grey literature using the Prisma guideline (14). A scoping study is justified here since it aims to map rapidly the key concepts underpinning a research area and the main sources and types of evidence available, especially where an area is complex or has not been reviewed comprehensively before (15). Furthermore, it is necessary here to search the grey literature, as the subject of this study have a practical perspective.

Find the relevant studies, through the usual means. The scientific scoping review was realised the 26th of June 2020 to assess the current practices in terms of evacuation of seniors in case of fire in private seniors' residences and long-term care home. Supplementary Table S1, shows the four different databases used for this research: PubMed, CINAHL, PsycNET and Web of Science. The basic keywords used in those databases were separated in four concepts (Seniors, Location of residence, Fire, Evacuation) and additional terms have been used in PubMed, CINAHL and PsycNET, according to their respective thesaurus, to improve the research. Additional articles found in the bibliography have also been considered. The scoping review with grey literature was realised using 4 different ways as presented in Table 1. To begin with, some information was given by experts and partners who work in the field of fire evacuation for seniors. Then, a research using the advanced search of Google Scholar was done the 21st of September 2021 in English and in French. The keywords were based on the terms used in the previous scientific review and identified by trial and error. For the English research, the search equation used was "evacuation fire senior residence" while in French, it was its translation "*incendie évacuation aînés*

TABLE 1 Data sources, date and research equation for grey literature related to evacuation in case of fire in private seniors' residences and long-term care home—English and French.

Source	Date of search	Research equation
Specific search in google	20 September 2021	- Évacuation aînés site:cisssca.com - Gouvernement du Québec incendie aînés - Évacuation aînés site: Québec.ca - Gouvernement du Canada incendie aînés - Évacuation aînés site:canada.ca
Experts and partners		- NA
Google scholar		- Evacuation fire senior residence - Incendie évacuation aînés residence
	14 September 2020	- (Dispositif OR Device OR Gadget OR Apparatus OR Equipment) AND (Évacuation OR Evacuation OR Movement OR Transportation OR Carrying) AND ("Personnes âgées" OR Aînés OR Elders OR Senior OR Bedridden OR Disabilities) AND (Urgence OR Emergency OR Crisis OR Danger* OR Fire) - (Device OR Gadget OR Apparatus) AND (Evacuation OR Transportation OR Carrying) AND (Elders OR Senior OR Bedridden OR Disabilities) AND (Emergency OR Crisis OR Danger* OR Fire)
Orbit		- (Dispositif OR Device OR Gadget OR Apparatus OR Equipment) AND (Évacuation OR Evacuation OR Movement OR Transportation OR Carrying) AND ("Personnes âgées" OR Aînés OR Elders OR Senior OR Bedridden OR Disabilities) AND (Urgence OR Emergency OR Crisis OR Danger* OR Fire)
EspaceNet		- (Device OR Apparatus) AND (Evacuation OR Transportation OR Carrying) AND (Elders OR Senior OR Bedridden OR Disabilities) AND (Emergency)

residence". Using the principle of data saturation, the first 5 pages of Google, with ten documents each, in the two languages were kept. Furthermore, specific searches in Québec's and Canada's governmental websites were done using Google (better search engine then most governmental websites). More specifically, a search was also done in the Integrated Health and Social Services Center of Chaudière-Appalaches (CA) website. Indeed, the region of CA in the province of Québec, Canada, is currently implementing a number of experimental measures for the evacuation of seniors. Finally, a specific search was conducted on Orbit, EspaceNet and Google Scholar to generate ideas for concepts that are currently used or could be used to evacuate seniors or PWD making them more difficult to evacuate. The research equations were refined using the same process as for the main research question.

TABLE 2 Inclusion and exclusion criteria for scientific and grey literature.

Inclusion criteria	Exclusion criteria
1. Mainly private seniors' residence and long-term care home or equivalent setting. Other health care settings are accepted	1. Evacuation takes place over several days or they had several days' notice (evacuation is not rushed) (e.g., hurricane, forest fire approaching…)
2. Addresses evacuation of seniors or people with mobility impairments or with cognitive issues requiring care	2. Article written in a language other than French or English
3. Addresses protocols, guidelines, etc. for evacuation	
4. Discusses alternative evacuation procedures or tools	
5. Discusses statistics related to evacuation	

Select the studies that are relevant to the question(s). For both scoping reviews, to ensure a solid internal validity, the articles were sorted out independently by two of the co-authors using the inclusion and exclusion criteria presented in Table 2 and according to the Prisma guideline (14). Figure 1 shows the steps of PRISMA. For the scientific revue, 503 articles were found, but 41 where duplicate. Of the remaining 462, a first selection was made by analysing the title and abstract to keep 87 of them. A second selection was done after reading the full text and reduced the number of articles to six. However, three articles found in the scientific revue where add to the grey literature revue. For the grey literature, 144 articles were found with five duplicates. A first selection was done by looking at the title and an overview of the text. Of the 139, 66 were kept and two more articles were added from bibliography. The second selection was done by analysing the documents using the five criteria of the AACODS checklist (Authority, Accuracy, Coverage, Objectivity, Date and Significance) (16). In this checklist, all articles that had a "No" on the significance category, were rejected, as well as articles that had more than two "No" in the other categories. For the articles that had only one, it was looked at carefully to decide if it was accepted or not. Of the 66 documents to be rated, 19 were included in the grey literature revue and seven where add to the scientific review. Thus, in total, 13 articles were kept for the scientific review and 22 for the grey literature review. Throughout the process, if any disagreements between the two readers occurred, a consensus

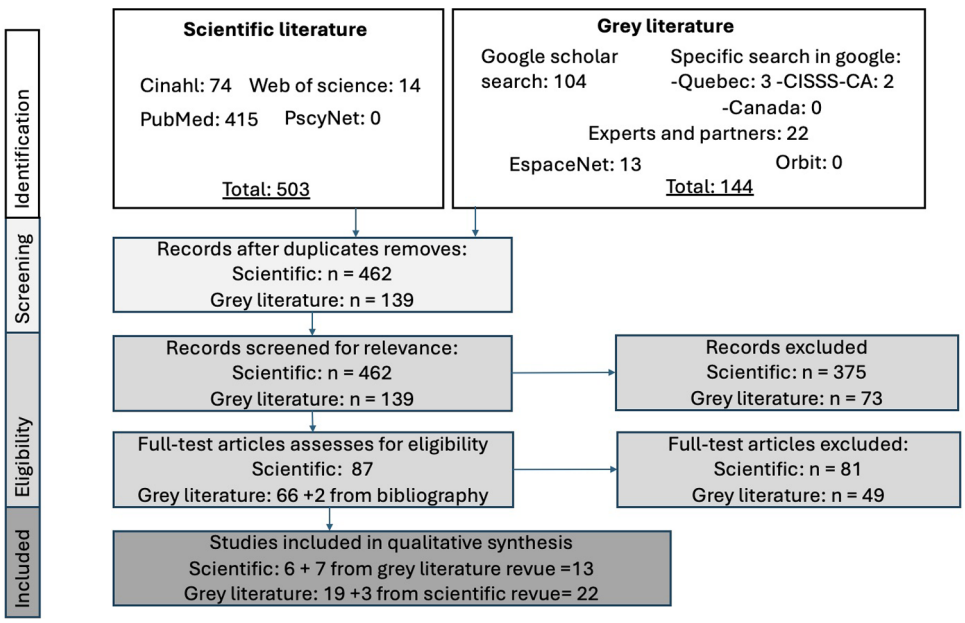

FIGURE 1
PRISMA flow chart illustrating the different phases of the selection process of relevant studies on fire evacuation in private seniors' residences and long-term care home for the PWD and seniors and the associated numbers.

was reached following a discussion between the two. If necessary, a third co-author was brought in to settle the issue.

Chart the data, i.e., the information on and from the relevant studies. Data extraction was done by two co-authors and transcribed in Supplementary Table S4 (scientific literature), 5 (grey literature) and 6 (equipment) and can be found in the Supplementary Material. The first papers were looked at by each co-author and compared together to ensure the same understanding of the table and the important information to gather. The results column in the Supplementary Table S4 and S5 was created using the Person-Environment-Occupation model (17), since it is a model commonly used by occupational therapists, of whom two authors are. For the purpose of this paper, the term occupation is referred as the action of practicing/learning evacuation techniques as well as performing the evacuation itself. It allows for a focus on the individual by highlighting the interactions between these three concepts and thus makes it easier to identify the barriers and facilitators present during an evacuation and during the application of the learning strategies. In the case of patents, a description of those and of their utility was add in Supplementary Table S6.

3 Results

Collate, summarize and report the results. For scientific results in Supplementary Table S4, 13 studies are reported. All research designs are exploratory, since there were three surveys, two case studies, one observational study, three qualitative research, one retrospective study report, one pre-post study design and one repeated measure randomized block experimental design. Samples varied between nine and 416. For results in Supplementary Table S5, the grey literature where mostly guides (four government guides and one evidence-informed recommendations summary), documents describing the situation of seniors in case of firing (one review of the situation, one final research report, one doctoral dissertation, one summary of government statistics) and one policy perspective. For results in Supplementary Table S6, the 12 documents are patents. Results will be summarized regarding the three research questions.

3.1 Existing fire evacuation learning strategies used with PWD and seniors

There is currently a gap between perceived and real preparedness as shown by the difference between the disaster plans and the result of the drills, specifically, in the case of dementia-specific awareness (18). Despite this fact, several methods are used to limit the impact of a fire, both in terms of prevention and to facilitate evacuation.

3.1.1 Drills

Evacuation drills are currently used but are also a debated method. Although it seems to help seniors to learn evacuation methods and safety tricks, few of them participate in it (18, 19). Moreover, there are risks to their physical and psychological health due to the stress involved in practising evacuation (18, 20). On the other hand, verbal or written instructions alone are also not enough, hence the importance of drills (21). To be effective, these exercises should be done at least once or twice a year (22, 23). At some of those, it was noted that there were increased numbers of people being advised by fire marshals during the practice and it was often rare that residents were evacuated to the end or to the nearest safe area. Indeed, they were often all brought to the same place, even if another area was closer (24). Another method of carrying out these practices is to include only staff. This helps to educate them on how to respond to a fire situation and how to deal with the residents (25). This type of training should be carried out minimally when there is a new employee and especially when there is a big change in personnel (23).

3.1.2 Training

Training beside drills should be given to residents and care-providers (21, 25–29). It should include a diversity of resources (26) and use various senses (21) to make learning easier for them. For example, a two-day training program to train staff, including a teacher's guide, a DVD of instruction and a CD containing other useful resources seem to work to give care-providers a better understanding of the disaster plan and of the best approach in case of fire. Inclusion of specific methods on training adult learners is also beneficial (27). In terms of content, those trainings should explain the four stages of evacuation (detection of the alarm/fire, understanding and undertake the evacuation, moving, relocating) included in the safety plan to help the staff and the residents understand the particularity of each stage and the procedures to follow (28). Furthermore, those instructions should be placed on each floor of the residence (28). Indeed, easy-to-access information is a good way to spread the information (29). Care-providers should also have training on how to respond and guide person with Alzheimer's disease (29) and how to help mitigate psychological distress and anxiety (29). It is recommended for people with dementia to give them calm and proper instructions, lots of reassurance and close supervision. It is important to have a good identification of all the residents and to include specific training to deal with behavioural symptoms (18). In addition, a suggested evacuation method to teach is to first assist residents near the fire and then evacuate the other systematically (23). It is also recommended to match the evacuation speed at a level that minimises risks for seniors (30). Furthermore, education on evacuation methods should no longer be only provided by first-responding agencies, but also by other partners to improve the dissemination of information (29, 31). An example would be to use the care-providers, who are known by the residents, to teach (26).

3.1.3 Promotion of a good fire safety plan

It is important to promote a good fire safety plan to help fire prevention and safe evacuation. This helps improve knowledge, role and responsibilities of everybody, good coordination of

actions and promotes a rapid response at the start of the fire (30). For example, in Québec, a revision of the plan is recommended at least annually (25) while evaluating the mandatory measures in place in PSR are the responsibility of the municipalities (32).

3.1.4 Research

Research should be promoted to support the development of a framework to measure the levels of preparedness of care institutions and to use the existing evidence to support planning and regulation in terms of fire prevention (29).

3.2 Barriers and facilitators for PWD and seniors' during fire evacuation and learning strategies in PSR and LTCH?

3.2.1 Barriers for seniors' fire evacuation in private seniors' residences and long-term care home

3.2.1.1 Personal factors

Several personal factors may influence the performance in an evacuation. To begin with, many seniors will hesitate before exiting at the sound of the alarm and need additional guidance or encouragement before exiting (24, 33). Thus, some of them, lose several minutes, putting their lives at risk (33). Secondly, in terms of preparation for a disaster, motivation would not be influenced by experience or taught knowledge. Indeed, the uncertainty that it will happen as well as the probability of dying beforehand demotivates seniors (26). In addition, the anxiety associated with disasters, like a fire, can be so important that some may be too afraid to think about it, and thus, do not prepare themselves accordingly (26). Many also feel that it is not their responsibility to be prepared (26). Lack of participation in fire drills and unfamiliarity with the building fire plan are personal actions that directly increase the chances of death or injury in an actual fire (19). Furthermore, a perceived safety net provides a false sense of security and prevent them from fully understanding the risk of injury or death due to fire (19). The language barrier and the wide range of educational levels can also affect the implementation of a training programme for staff (27).

Several physical limitations can make evacuation more difficult. First, people with impaired mobility may be at risk of falling, especially on stairs, given that lifts are unavailable during a fire (21, 28). Others may be unable to manipulate certain handles or doors on the escape route, particularly due to diseases such as arthritis (21, 28). Respiratory problems may also make evacuation more difficult by increasing the demand for oxygen due to the physical effort required and the level of stress. When fire and smoke are present, symptoms of respiratory dysfunction and distress are also exacerbated (21). People with hearing problems may not hear alarms or additional information given during the evacuation (19, 21, 28, 30). Those with visual problems may have difficulty orienting themselves and reading maps and signs, especially due to lack of lighting and smoke (21, 30). Furthermore, in emergency situations, bedridden or severely disabled residents may be totally dependent on the staff, leaving those with milder disabilities unattended (19).

Cognitive problems as well as dementia can also affect evacuation. Indeed, these individuals have special needs during an evacuation and are more vulnerable, due to difficulties in concentration (18, 30), comprehension (28, 30), memory (21, 30), following instructions (18) and due to behavioural problems, such as anxiety, distress, wandering or agitation (18, 21). In addition, high anxiety conditions make memory issues worse (30). Sleep inertia can also occur for seniors and reduce physical and cognitive performance for at least 30 min after awakening (21). Medications can also play an important role in the cognitive ability of seniors, including decreasing their reaction time and alertness.

3.2.1.2 Environment factors

At the environmental level, it has also been found that most fires in private residences in Québec start in residential areas, mainly in the kitchen and bedroom (34). Several environmental barriers can hinder drills or the evacuation itself. First, at the institutional level, the lack of time to organise drills (27), the lack of resources in residences (35) and the shortage of staff, mainly at night (19, 24), are the three main difficulties identified. A lack of regulation, mostly in relation to people with disabilities, is also present (36). Secondly, the lack of preparation and materials is also problematic. Indeed, ineffective manuals, not having cards to indicate empty rooms and locked doors without an accessible key, are all elements that can hinder an evacuation for employees. Poor lighting at the evacuation plans can make it difficult for residents to evacuate (20). Thirdly, on an architectural level, the type of construction often used for residences common areas, for example, large rooms (cafeteria, playroom, lounge, chapel, etc.) and long, wide corridors, favour the spread of fire and smoke (19, 37). The lack of sprinklers in many residences (19, 28, 35) is also problematic, as is the absence of an alarm system linked to the fire department, preventing a rapid response from the firefighters (28). Moreover, buildings without firewalls prevent the effective implementation of horizontal evacuations, which is easier to achieve than vertical evacuations (28). Finally, clutter, grouping, lack of handrails and visibility, are all factors that can hinder an efficient and safe evacuation (28).

3.2.2 Facilitators for seniors' fire evacuation in private seniors' residences and long-term care home

3.2.2.1 Personal factors

In terms of personal factors, it is recommended that managers ensure that their employees and replacements have received fire safety training (22, 38) and that residents are informed about fire safety and good behaviour (22). This ensures that everyone knows their role and avoids confusion, thus limiting the danger to residents and employees (38). Good communication between staff, firefighters and the incident coordinator is also desirable to facilitate evacuation (38). In addition, in the event of a disaster, it was found that older residents are willing to follow the instructions of government and municipal response agencies (fire and police departments, military), especially among those with previous disaster experience (31). According to Proulx (33), 89% of people in a fire practice followed instructions from the voice

communication system and 64% of them found the information useful. From the same study, 81% said they would like to obtain more information on fire safety.

3.2.2.2 Environment factors

It was found that in most fires between 2016 and 2019 in private seniors' residences in Québec, the smoke alarms and the alarm system worked well (34). In addition, even though private seniors' residences often had a less developed security system than public ones, people felt safe because of the presence of staff (32). Several environmental facilitators can play a role in evacuation. First, a good communication system (21, 23, 38), with a clear and defined ordering hierarchy (21, 37) greatly assists the police and staff in evacuating residents. Secondly, an audible alarm system and voice communication system are effective means, especially when coupled together, to warn residents, even those with hearing problems (33). The alarm system can also include a strobe light to warn people in a deeper sleep (e.g., medication) or with hearing problems (21). In addition, the fire service should be alerted first by the alarm system rather than by employee action (23). Thirdly, safety can be greatly increased by high standards of construction (fire-resisting construction and compartmentation, incorporating sub compartments with a small number of bedrooms, fire-rated, bedroom doors with smoke seals and automatic closure on alarm). This protects residents and makes evacuation easier for employees (23, 37). Sprinklers and free-swinging automatic door closers also reduce the spread of fire and smoke (23, 37), while the presence of handrails and emergency lightning in exit door and corridor facilitate the movement of people with reduced mobility (21). Fourth, a clear evacuation plan (21, 22, 32) and maps showing a well-marked and lit path is very important to facilitate evacuation as it allows a better understanding of the path to be followed by the residents (21, 30).

3.3 Existing equipment or invention

Several inventions have been tested over the last decade to help evacuate in emergency situations people with or without disabilities. Twelve patents have been found and can be regroups into six types of equipment. Some of them are similar to a chair, making it easier to get down the stairs than a manual descent, promoting ideal positioning of the carer and improving comfort for the resident. This type of chair can be motorized or not (39–41). About these types of chairs, a focus group with firefighters also pointed out that they preferred devices with a longer extension at ground level in order to be able to cover three steps at a time, thus offering better stability to the device (40). There are also different types of boards to facilitate the transport of residents, some of which can be slid along the floor by a single carer (42) while others must be lifted by two people (43, 44). An apparatus can also be installed on beds to help transport bedridden people (45). Others allow residents to be lowered by means of a lift system, which can be either inside (46, 47) or outside the building (48, 49), or by using a zipline (50) or a tube on the side of the building with a padded sleeping bag (51).

4 Discussion

This scoping study has answered the first research question since it identified three kind of learning strategies (drills; training; and the promotion of a good fire safety plan) The second research question has highlighted nine personal barriers and 11 environmental barriers, as well as four personal facilitators and ten environmental facilitators for seniors' fire evacuation strategies in PSR and LCT homes. The last research question pointed out six types of equipment/invention through 12 patents: chairs, boards, apparatus for beds transportation, lift system, zipline and tube. Given those results, the discussion will be presented in two main parts: *prevention and learning strategies* regarding what to do in case of fire; and tools uses to help *evacuate* PWD and seniors.

4.1 Recommendations for prevention and learning strategies

One of the major points that emerges is it seems that there is a crying need for awareness-raising at several levels. Indeed, on an individual level, it is necessary to ensure that seniors understand the implications of not being prepared in case of fire: they are not only putting their lives at risk, but also the lives of those who will come to try to help them. At the community and institutional level, we need to ensure that residences have the resources to train their staff and residents in fire prevention and evacuation methods. Indeed, it seems there is also a need to continue to improve the learning strategies currently used. One way to do this would be to not only rely on drills, but also to add training and practices provided by the community. An example of such training could be a peer training program (52) to involve more seniors in the process and to build on social reinforcement as an awareness raising method. Considering the difficulties of the residents, especially at the cognitive level, during drills and training programs it is essential to ensure that they understand and integrate the lessons. For example, short learning segments could make it easier to keep their attention and concentration, thus maybe facilitating their understanding of the subject (30). To ensure that as many people as possible participate, it could be possible to implement these training capsules through already organised group or social activities.

Given the complexity of the problem, a multi-approach is necessary to help both residents and staff to learn. Including different senses and ways of learning would give a more complete experience and help build on each person's strengths. Evacuation drills remain an essential learning factor for residents and staff, but on the other hand, they can be harmful to the seniors, both physically and psychologically. It would therefore be interesting to develop alternatives methods of giving them practical training (53). For example, the creation of a serious games (54), using technology as a medium, could simulate a fire situation in a realistic way and offer a learning opportunity with less risk for the seniors. In addition, this type of practice could also be developed for staff. Indeed, conducting a drill is time

consuming and difficult to organise at high rate of occurrence (10, 11). Although this has not been tested yet, a serious game simulating drills could be a venue to explore, by provide training for new staff and serve as a reminder to older staff, potentially reducing the need for frequent actual real drills.

Another area that needs improvement in terms of prevention is the environment. The residences must have the resources to create the safest possible environment and have the necessary equipment to evacuate quickly, efficiently and in a manner that is safe for all. It is important to ensure the best architectural layout and equipment to facilitate communication between firefighters, employees, and residents. Many alarm systems can be used to alert residents in different directions, but it is also important to ensure that these systems do not incapacitate others. High volume and strobe lights can be disruptive to some people, especially those with sensory problems such as autism spectrum disorders or intellectual disabilities (55–57). This seem relevant to be taken into consideration mainly because the longevity of these two populations has increased significantly (58, 59), and they may find themselves more often in residences. It is also important to ensure that systems to slow the spread of fire are not harmful to residents. Indeed, due to their physical and sensory difficulties, some tools can become a nuisance. For example, it is also possible that sprinklers may create steam, which could lead to poor visibility and make breathing more difficult for those with respiratory problems (6).

4.2 Recommendations for tools used during evacuation

In order to help in the evacuation of the seniors in the event of a fire, 6 different solutions (chairs, boards, equipment for beds transportation, lift system, zipline and tube) were found in this review. However, their use has been little documented in the literature. One possible explanation for this is the cost associated with these equipment's. Indeed, many of them may be expensive and residences cannot afford them. Thus, it would be beneficial to continue to work on the development of evacuation tools/solutions for the seniors, taking into consideration not only the cost, but also the physical difficulties, such as decreased overall strength, grip and breathing problems, and cognitive difficulties, such as anxiety, dementia and comprehension problems. These prototypes should also take into consideration the level of learning required for use, the usability and inclusiveness of the equipment for various clienteles and staff who will manipulate them, as well as the environment in which it is used, both in terms of the type of building and the weather conditions if it is outdoors. We can especially think of the impact of winter on the usability of the equipment in the case of northern countries. To ensure that theses inventions are used, partnerships could be formed with governments, community organizations along with public security and firefighters' departments to facilitate the dissemination of those evacuation methods in private seniors' residences and long-term care home. Some of these partnerships could be used to help finance the cost of the equipment, while others could be used to help raise awareness of the need for proper equipment and how to use them.

4.3 Limitations of the study

This scoping review only sample articles from certain literature databases and journals, along with a limited number of pages from Google Scholar, and English and French-only documents or articles, which may compromise to some extent, the external validity of the review.

5 Conclusion

This review helped to identify ideas of what is considered as current learning strategies when it comes to teach fire evacuation in homes for the seniors. It has also highlighted that a multitude of barriers and facilitators may affect the learning process of the protocol, but also the evacuation itself. There is still a long way to go to ensure that the learning strategies used and evacuations themselves are safe for all. Increasing awareness is a pivotal first step and increasing the amount of scientific literature on the subject will help to achieve this goal. The development of new methods that are more adapted to the experiences of seniors, such as a formation that considers their strengths and difficulties and that also focuses on their lifestyle to increase their adherence, might be a way to make it easier for seniors to learn the evacuation guidelines. In order to ensure that the formation is as effective as possible in transferring knowledge, it would be wise to include seniors in the creation of the course. Research, development, and dissemination of new evacuation tools would also be essential to enable safe and effective evacuation.

However, little information was found on the content of the training courses, what staff and residents should be taught and what specific guidelines should be followed in the event of a fire. Further research on this subject could therefore enable better dissemination of the guidelines and prevention methods to be followed and thus prevent deaths among a vulnerable and growing population.

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Supplementary material

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Video games and disability—a risk and benefit analysis

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Purpose: Over the past decades, video games have become a substantial part of the entertainment industry. While ubiquitous, video game participation remains low among people with disabilities amid potential negative effects. This article analyzes the risks and benefits that video games may present to individuals with disabilities.
Methodology: In this conceptual article, we explored the literature pertaining to video games and disability. To better understand the impact of video games on individuals with disabilities, we focused on the unique features of video games through the lens of the Self-Determination Theory.
Findings: Our findings show that individuals with disabilities are most at risk from excessive video game use, leading to increased aggression, sedentary behavior, and negative impact on academic performance. Identified benefits include promoting physical rehabilitation and psychological well-being, improving cognitive abilities and emotional regulation, and utility in promoting exercises, and managing chronic pain.
Originality: This article presents a number of strategies and resources to help guide individuals with disabilities, educators, practitioners, and researchers in maximizing the benefits of video games while controlling the risks.

KEYWORDS

video games, disability, rehabilitation, risks, benefits, self-determination theory, motivation

Video game and disability—a benefit and risk analysis

The video game industry has grown exponentially over the past few years, and there are no signs of slowing down (1). The revenue generated by the video game industry is more than that of movies and sports combined (2). As Pallavicini et al. (3) mentioned, video games have become a common daily activity for most adults, and the video game population is equally distributed across gender and age. The number of people playing video games is even more robust because of the COVID-19 pandemic, during which other forms of entertainment, such as movies and live sports events, were restricted (4).

While video games seem ubiquitous, not everyone has equitable access to them. A plethora of literature points out that individuals with disabilities have lower participation in video games [e.g., (5–7)]. Individuals with disabilities typically encounter two major challenges when playing video games. First, not all video games are accessible. As Grammenos et al. (7) described, video games have higher or unique demands for individuals' motor, sensor, and mental skills. For example, in some games, players need to press the exact button(s) on a controller at a specific time to achieve the objectives. Super Mario Bros series, as an example, require players to control the main character to run and jump precisely to pass the level. The precision

of hand-eye coordination and short response times needed for mastering the games subsequently influence the overall playing experience. In addition, individuals with cognitive impairments may find it challenging to navigate games with puzzle quests, wherein players must fully comprehend and follow the instructions to achieve the objectives (8). Compulsive use is another common concern that may hinder individuals with disabilities from engaging with video games healthily. This concern is particularly true for younger individuals with developmental disabilities. For example, Mazurek and Engelhardt (9) indicated that some believe playing certain types of video game leads to certain behavioral problems, especially those with developmental disabilities such as autism spectrum disorder The reported issues range from inattention (10) and oppositional behaviors (9) to video game addictions (11, 12).

Despite these concerns, researchers continue to invest in what video games can offer for people with different abilities. Some studies used video games as a motivator to promote academic learning [e.g., (13–15)]; to improve cognitive abilities [e.g., (16, 17)]; and to enhance physical strength [e.g., (18, 19)]. The undeniable benefits, in conjunction with potential risks, have yielded much discourse supporting and against the use of video games in educational and clinical settings. Whether to leverage the utility of video games or altogether avoid them becomes a result of personal choice and clinical judgment of educators, practitioners, and individuals.

Purpose

Considering the contentious nature of video games, this article examined studies published in the past two decades that explore the relationship between individuals with disabilities and their engagement with video games. Specifically, we searched databases, including Google Scholar, ProQuest, EBSCOhost, and ResearchGate, with keywords including disability, rehabilitation, video games, and gamification. For a more focused search, we set the search limitation to include only peer-reviewed journal articles and articles written in English. Although we attempted to capture as fully as possible, readers should be aware that this article is not a systematic review of the literature but a summarization of what we discovered from the literature. Therefore, interpreting our findings and suggestions should be cautious.

In this article, our primary aim is to illustrate that, despite being controversial and raising certain concerns, video games can serve as a valuable tool due to their unique features for motivating engagement. We argue that whether to play video games is not a simple all-or-none decision; instead, the key rests on making players with disabilities aware of video game benefits and risks while facilitating their informed decisions. In addition, we seek to draw attention from practitioners, researchers, and educators to leverage video games as valuable tools and advocate for equitable access to the digital entertainment world for individuals with disabilities. In this article, we (a) discuss the evolution of video games, (b) discuss the uniqueness of video games from a theoretical standpoint, (c) explore the risks and benefits associated with video games, and (d) provide practical strategies and resources for leveraging video games that maximize the benefits while controlling the risks.

The evolution and uniqueness of video games

As the digital world evolves, video game technology has also advanced from traditional two-joystick and one-monitor entertainment to a more sophisticated and immersed player experience. To date, gaming consoles such as PlayStation and Xbox offer a much higher resolution picture (4 K) with vibrant colors, significantly improving players' immersive experience. In addition, various control mechanisms have been introduced to allow for real-life simulation, such as a steering wheel for driving games and simulated instruments for music games. The evolution of virtual reality technology pushes a step further for a more immersive experience by submerging users in a three-dimension world. To accommodate individual preferences in content and style of play, video game genres are many and varied, including action, adventure, role-playing, puzzle, simulation, strategy, and sports (details for each type of video games can be found in Table 1). A single-player game is optimal for individuals who enjoy playing the game by themselves; for those who enjoy playing with friends, cooperative games (or "co-op games") can be played. If the person prefers to play cooperative games but cannot find anyone nearby, an online game can be an option. More recently, accessibility features were built natively in some games to assist individuals with various disabilities. For instance, high-contrast color and captioning can be enabled to assist individuals with sensory impairments, and button remapping and adaptive controller can be useful for those with finger dexterity challenges. The abundance of options satisfies various preferences and abilities, thereby providing a great deal of freedom for users to choose whatever, however, and whenever they would like to play these games.

Theoretical perspective—self-determination theory

The freedom of choice, which gives players a sense of control, is perhaps best understood from the *self-determination theory* [SDT; (20)]. This empirically derived theory depicts the psychological needs of an individual when engaging in an activity. The satisfaction of these psychological needs leads to either motivating or discouraging continue engagement of the activities. When these psychological needs are satisfied, the individual feels empowered by self-determination. On the other hand, when the needs are somewhat deprived, the individual may choose, if allowed, to avoid such activities. These psychological needs can be categorized into three dimensions: autonomy, competence, and relatedness (20) (see Figure 1). Autonomy pertains to an individual's volition for engaging in specific tasks. Therefore, the individual may do certain things voluntarily or, in extreme cases, be coerced. In the context of playing video games, as Ryan et al.

TABLE 1 Video game type.

Game type	Descriptions	Examples
Action games	Action games prioritize physical challenges, hand-eye coordination, and reaction time. Players typically navigate levels, fight enemies, and complete tasks that require swift reflexes.	• Super Mario Bros • Devil May Cry
Adventure games	Adventure games prioritize story-driven experiences, puzzle-solving, and exploration. To advance through a storyline, players usually engage with characters and objects.	• The Legend of Zelda • Life is Strange
Role-playing games (RPGs)	In RPGs, players can become characters in make-believe worlds. These games often feature character development, storytelling, and decision-making that have an impact on the game's outcome.	• Final Fantasy • Elden Ring • Mass Effect
Simulation games	Simulation games imitate real-world activities or systems. Players engage in tasks ranging from managing cities and farms to flying airplanes or driving vehicles.	• The Sims • Microsoft Flight Simulator
Strategy games	Strategy games require players to plan and make decisions to achieve specific goals. They can be turn-based or real-time, involving resource management, tactics, and sometimes warfare.	• Civilization • StarCraft • Age of Empires
Sports and racing games	Sports games simulate real-world sports, while racing games focus on competitive racing experiences. These games often feature realistic physics and gameplay mechanics.	• FIFA • Gran Turismo • Mario Kart
Fighting games	Fighting games involve one-on-one combat between characters, each with unique moves and abilities. Players compete to deplete their opponent's health bar.	• Street Fighter • Mortal Kombat
Horror games	Horror games aim to create a sense of fear and suspense. They often involve survival elements and focus on storytelling to immerse players in a tense atmosphere.	• Resident Evil • Silent Hill
Massively multiplayer online role-playing games	MMORPGs are online multiplayer games where large numbers of players interact in a persistent virtual world. They often involve character progression, social interaction, and cooperative play.	• World of Warcraft • Guild Wars 2
Puzzle games	Puzzle games challenge players with logic-based problems and tasks. They can range from simple puzzles to complex brain teasers.	• Tetris • Portal

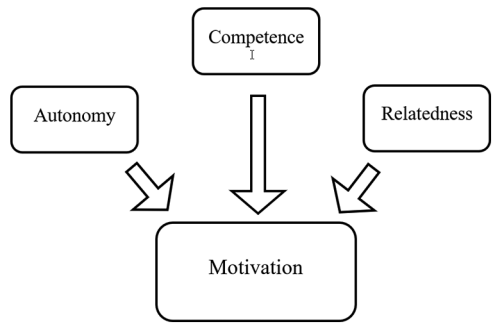

FIGURE 1
Self-Determination theory. The three elements, autonomy, competence, and relatedness, that drive people's motivation in self-determination theory.

(21) described, almost all cases are voluntary; therefore, the need for autonomy is easily satisfied.

Competence pertains to one's need to be challenged, providing a sense of achievement. Based on effort justification theory, Inzlicht and colleagues (22) explained that an individual's effort toward a given pursuit would add value to its outcome. Therefore, completing an easy task may not be as satisfying as completing a challenging task. In the video game sphere, players usually start a game from an easier level, and by design, most games increase the level of challenge as they progress. As players progress in the game, the sense of achievement becomes a natural gaming experience.

Relatedness pertains to the need for belonging or connecting with others. According to Ryan et al. (21), video games effectively meet this need from two perspectives. First, computer-generated personality and artificial intelligence can produce a sense of belonging when players are immersed in the games. For example, in a role-playing game (RPG), players may immerse themselves in the stories and befriend non-player characters (NPCs). Another source for the sense of relatedness can be found in multiplayer or online games. As Hsu and Lu (23) described, the online game community provides players with a sense of group cohesiveness and, in turn, positively affects players' loyalty and motivation to the game.

The capacity of video games to satisfy an individual's psychological needs of self-determination is a double-blade sword, however. For example, a sense of achievement obtained from passing a game level can be uplifting, but if the pursuit of such a feeling gets in the way of daily life, it becomes a problem. We believe that only by understanding the risks and benefits of video games, we will be able to help individuals with disabilities make informed choices. To this end, we discuss the risks and benefits associated with video games in the following section.

Risks of video games

The available literature on the risks of video games examines their relationship to excessive use, their associations with aggressive and sedentary behavior, and the academic problems that can develop because of overuse.

Excessive use of video games

It should be noted that excessively playing video games differs from other forms of addiction. Video games, unlike substances such as alcohol and drug, do not directly manipulate neurotransmitters or alter brain functioning. Continuing to play video games is typically motivated by in-game rewards (24). In the context of SDT, it can be understood that playing video games satisfies psychological needs that are otherwise difficult to achieve. Typically, an individual would fulfill self-determination needs across various life events such as education, work, and recreation. Hence, a good balance can be maintained. However, when playing video games becomes the dominating source of self-determination need, it becomes problematic (25). Due to its impacts, problematic video game behavior and pathology have caught much attention lately (24).

In addition, the diagnosis standards, such as the 11th revision of the International Classification of Diseases (ICD 11), have also included gaming disorder as a formal diagnosis, defining it as a gaming behavior of sufficient severity to result in significant impairment in areas of function. Similarly, the Diagnostic and Statistical Manual of Mental Disorders-Text Revision (DSM-5 TR) also identifies Internet Gaming Disorder (IGD) as a condition that requires clinical attention (26). A recent study conducted by Masi et al. (27) reported children with attention-deficit/hyperactivity disorder (ADHD) are vulnerable to excessive use of video games compared. Similarly, in a survey of 23,533 adults, Andreassen et al. (28) found that ADHD, obsessive-compulsive disorder (OCD), anxiety, and depression are associated with problematic use of social media (15%) and video games (7%).

However, the prevalence and the etiology of problematic use of video games may be debatable (29). In a comprehensive review, Przybylski and colleagues argued that the prevalence rate may not be accurate as relevant studies do not distinguish between passionate engagement and pathological symptoms. Specifically, Przybylski et al. (30) indicated that of those who play games, more than two in three did not report any symptoms of IGD. Furthermore, they also suggested that only a small proportion of the general population—between 0.3% and 1.0%—may qualify for a potential acute diagnosis of IGD. Similarly, although pathological internet use (PIU) is commonly observed in those who play online games (31), it is questionable to attribute the problem strictly to video games. For example, researchers argued that the "gaming" component of the video game does not cause PIU. Instead, it is the interactive feature, such as online chatting and messaging, which generates a sense of companionship that causes the problem (32).

Aggressive behavior

Compared to more passive media such as television and movies, the interactive nature of video games may increase the likelihood of aggressive behavior by allowing players to engage in behaviors that are not otherwise socially accepted in the real world (33). About 90% of the games contain some form of violent content, and 40% include serious violence against other characters (34). This is alarming because several studies have found connections between violent video games and delinquent or violent behaviors (35, 36). Specifically, an analysis of 3,372 Flemish adolescents revealed that violent video gaming was positively related to individual delinquent behavior. In contrast, nonviolent video gaming was not found to be related to problematic behaviors, suggesting that the content of video games matters (36). Similarly, Anderson and his team (2010) reported that violent video game content was positively related to aggressive behaviors, thought patterns, affect, and a lack of prosocial behaviors (e.g., empathy) in real life.

However, while some research suggested that violent content in video games may promote higher levels of aggressive behaviors in real life, others argued that the strength of its influence is debatable. For example, in a study of youth in eighth and eleventh-grade students, DeCamp and Ferguson (35) noted that violent video games were a weak predictor for violent behaviors compared to other predictors (e.g., home environment, relationship with parents, and demographics). Specifically, factors such as poor family relationships and prior abusive experience were far more critical regarding youth violent behaviors.

Sedentary behaviors

Sedentary behaviors, like watching television and playing video games, are highly prevalent in youth and may be associated with physical and mental health markers. In a systematic review, Kontostoli et al. (37) observed that the time children and adolescents spent playing video games limited their time for healthier physical activities, raising health concerns such as cardiovascular disease (CVD). Similarly, in a study of Korean adolescents, Byun and colleagues (38) found that participants' time spent watching TV or playing video games was associated with the risk of high adiposity. Consistent results were reported in European and American children and adolescents (39, 40). Recognizing this potential issue, video game technology has evolved creatively to battle it. For example, some games would prompt players to rest after a continuous playing period and those that require players to interact with full-body movements.

Poorer academic performance

In the United State, it is reported that 60% of video gamers are below 34 years old (41). Of these gamers, 40% are below 18. Due to the ubiquitous video game engagement among the young population, concerns regarding the impact of video games on academic performance are common. One longitudinal study conducted by Jackson et al. (42) sought to examine whether the time spent on Internet use and video game playing influenced the academic performance of 12-year-old youths for a year. As a result, video games were found to be negatively correlated with

academic performance. However, this relationship only existed among those who had a lower GPA to begin with. Importantly, Jackson et al. (42) noted that using GPA as a single measure may be misleading, particularly for young children. For example, playing video games was found to be beneficial to these children's development of visual-spatial skills. However, these skills may not yet be part of the academic requirement at the 6th or 7th-grade levels; thereby, the GPA did not reflect the benefit. Nevertheless, the negative effect of playing video games on academic performance was echoed by many others across different age groups [e.g., (43–45)].

Benefits of video games

Despite the many risks associated with video games, many benefits have also been reported. For example, video games can be a vehicle for enhancing cognitive abilities, increasing emotional regulation, managing chronic pain, and promoting physical activity.

Cognitive abilities enhancement

The utility of video games to enhance human ability can be traced back to 30 years ago when researchers first used them to teach children communication and spatial abilities (46). The highly customizable content and interactive feature make video games unique when used as a training tool. Game designers can embed learning content in the game and provide immediate rewards when learners complete a required task. These features, from the lens of the SDT, really help promote the autonomy and competence needs of the users, and ultimately motivate users to continue their engagement. Leveraging this unique feature, researchers have also used video games to train people with disabilities. For example, video games were found to be effective for developing social skills in children with dyslexia, learning difficulties, and autism spectrum disorder (ASD) (47–50). In a recent study, Beaumont and colleagues found that children with ASD can benefit from video game-based social skills training, especially with parental involvement. Similarly, in a systematic review, Eichenberg and Schott (51) aptly indicated that video games, when infused with cognitive behavioral techniques, are valuable for improving behavioral, cognitive, and emotional outcomes of those with learning and cognitive disabilities.

In addition, Ashinoff and Abu-Akel (52) demonstrated using video games to improve the attention span among those with ADHD. Specifically, they explained that when individuals with ADHD play video games, their alpha and beta levels in the frontal lobe reduce. This reduction in alpha and beta levels signifies that the individuals can maintain their engagement in a given task effortlessly, hence achieving a hyperfocus status. Although the generability still needs testing, it shows promise for maintaining attention in the ADHD population.

Serious gaming

There is a plethora of research conducted on using video games for educational purposes [e.g., (53, 54)]. These are usually referred to as serious games, which are designed with educational goals, such as science, mathematics, languages, history, spatial problem solving, logic, and mental rotation skills while providing engaging, interactive, and fun learning environments for single or multiple players (53, 54). The utility of serious gaming has caught much attention in K-12 classroom settings, both mainstream and special education, for its unique features that create authentic learning situations, promote intrinsic motivation, and interactions to promote social learning and individualized learning (55). Serious games can be found in many settings, such as the military, medicine, and manufacturing (56).

For training individuals with disabilities, serious gaming can be helpful as well. For example, Papanastasiou et al. (55) reviewed previous studies and suggested that serious games positively influence the executive functioning of students with intellectual and developmental disabilities, ADHD, and ASD. Specifically, they argued that multi-sensory stimuli can accommodate students with different learning styles. From the lens of the SDT, video game-infused learning can promote autonomous learning, thereby motivating students' engagement. Papanastasiou et al. (55) reported that this type of learning can yield positive outcomes, including enhanced perception, attention and cognition, phonological skills, visual-spatial attention, increased social engagement, and independence. A more recent study also demonstrated positive outcomes from playing serious games, which results in improved attention, time management, and planning/organizing, and decreased hyperactivity symptoms among students with ADHD and learning disabilities (57).

Emotional regulation

Emotional regulation is the ability to monitor, evaluate, and control one's emotions. Emotional regulation is associated with several important outcomes, including psychological well-being, relationship satisfaction, and overall mental health (58, 59). In contrast, emotional dysregulation, which is commonly observed in ASD, ADHD (60, 61), and the chronic pain populations (62, 63), is associated with many forms of psychopathology and maladaptive behaviors (64).

In a systematic review, Villani et al. (65) found that video games have a lot to offer regarding emotional regulation. First, video games provide players opportunities to actively interact with the game, which directly influences their locus of control and sense of autonomy—a critical element of the SDT. Additionally, the exposure to negative emotional stimuli during gameplay (e.g., frustration during a difficult level in the game) offers an opportunity for players' ability to be aware of their emotional state (66, 67) and build resilience to frustration (68). Importantly, Gaggioli et al. (69) and Tunney et al. (70) argue that video games can be instrumental in training

emotional regulation because of their highly customizable features. For example, gradually adjusting the game difficulty levels to be harder and harder can be useful for building frustration tolerance.

Lastly, video games can also help people cope with stressors such as job loss (71) and bereavement (72). In a survey study, Iacovides and Mekler (73) explored the relationship between video games and their effect on players' coping mechanisms. Specifically, their attention was on whether the video game would help them escape temporarily from real-life distress. While escapism is often considered a maladaptive coping mechanism, the study argued that adequate escapism can be a healthy distraction that is much needed for some. As Kuo et al. (74) further explained, healthy escapism represents a temporary shift of attention from the self, which can be achieved by projecting oneself onto in-game characters. This escapism allows players to explore versions of their ideal or aspirational selves, thereby fostering a better self-understanding.

Chronic pain management

Chronic pain is a common symptom shared by people with various physical disabilities (75). It is associated with many negative outcomes, such as poor goal attainment (76), school performance (77) and social functioning (78). Chronic pain is also associated with higher rates of anxiety (79), insomnia (80), and depressive symptoms (81).

As early as the 1980s, Redd and colleagues (82) found that video games were an effective way to distract attention and manage pain. Since then, its applications for pain management have been widely used. For example, video games were found to be effective pain relief for patients going through unpleasant medical treatments such as chemotherapy (83, 84). Additionally, occupational therapists and physical therapists have used video games with burn patients (85) as a means of distracting from pain as well as rehabilitating physical strengths (86, 87). To this end, video games can be a non-pharmaceutical complementary intervention and can be easily integrated with existing medical procedures and therapies.

Increasing physical activities

Maintaining a regular exercise habit for a healthy lifestyle can be challenging for anyone. Willson et al. (88) used the SDT to explore factors influencing individuals' motivation to maintain exercise. In their analysis, although each element of the SDT interacts with the exercise motivation differently and may depend on the individual (e.g., females have a different competence needs than males for exercises), their influences are without question. Interestingly, as mentioned earlier, video games bear the capacity for fulfilling all three needs of the SDT. Therefore, using video games to motivate physical exercise can be an effective application.

Active Video Games (AVGs), also referred to as "exergames," consist of games that require players to exert physical energy to progress through the game (89). AVGs have been used in occupational and physical therapy settings for over 30 years. These game-based exercises are helpful for task-specific rehabilitation that aims to enhance function in hands and extremities (90, 91), movements, balance, and mobility after brain injury (92–94). In addition, research also shows that some games may improve physical fitness for wheelchair users with spinal cord injuries, nerve diseases, and multiple sclerosis (95, 96). Despite a small sample size, Singh et al. (97) demonstrated that playing interactive VR games would increase reaction time in adults with disabilities.

Aside from rehabilitative goals, AVGs provide an opportunity to engage in physical activities that otherwise might not be possible due to social distancing or other life commitments such as work and school (89). This increase in physical activity, in turn, can reduce depressive symptoms and improve mental health (98). Studies also show that participation in exercise games positively affects self-esteem and self-efficacy and may promote intrinsic motivation to continue exercise outside of video game play (99, 100).

Strategies and resources

It is clear that playing video games can yield both risks and benefits. The question is then how to maximize the benefits while controlling the risks. In the following section, we provide some strategies for leveraging video games' benefits and unique features. Specifically, we suggest to (a) form a well-defined purpose for playing video games, (b) be cautious of content and disability populations that are associated with risks, and (c) monitor and supervise the use of video games. Lastly, we recognize the fast evolving pace of video game technology. It is becoming challenging to stay updated without reliable sources of information. To this end, we would like to introduce a list of useful online video game resources that specifically aim to assist individuals with disabilities to engage in video games.

Well-defined purpose

People choose to play video games for several reasons, such as entertainment, education, social connection, rehabilitation, or any combination of these. While video games were originally designed to entertain players, their utility has since expanded. Although there can be numerous reasons for playing video games, it is helpful for players to identify the primary reason for playing them in a particular setting. As Nebel et al. (101) emphasized, explicit goal-setting would improve video game experiences by increasing motivation and lowering cognitive load compared to those without a well-defined goal. Similarly, Brusso et al. (102) highlighted the importance of realistic goal-setting to individual performance in video game-based training. Therefore, if the reason for playing video games is not strictly for

entertainment, a well-defined and explicit goal should be delineated to set realistic expectations and accountability. A well-defined goal would inform the outcome evaluation and monitoring, and help decide the types of games and the ways of interacting with them. For example, if the intent is to do more exercises or physical rehabilitation, AVGs (e.g., Just Dance, Ring Fit Adventure) would be ideal; if the individuals would like to enhance decision-making and critical thinking skills, puzzle and strategy games can be helpful.

Aware of the risks

Although video games can be helpful in many ways, their risks should be recognized and controlled. Importantly, attention should be given to two aspects: content selection and disability population. As Glaubke and colleagues (34) illustrated, 90% of commercial video games contain some level of violent content. Combined with the finding reported by Excelmans et al. (36) that violent video games may lead to delinquent behavior, victimization, and alienation, gamers should be selective of the appropriate content. In addition, certain disability populations (e.g., ASD, ADHD, OCD) are more prone to overuse of video game, IGD, inattention, and aggressive behavior (103). It should be noted that we are not arguing that video games should be avoided completely for these populations. Instead, close monitoring and supervision are needed.

Monitoring and supervising

As with many things, good things can quickly turn bad when used excessively without close monitoring and supervision. To maintain healthy video game-playing experiences, two aspects should be monitored: First, whether the purpose of playing video game is achieving the intended purpose, and second, whether the time spent playing video games is interfering with other life activities. It is important to design and implement the associated measurements when formulating the purpose for playing video games. In the context of educational video games, Padilla-Zea et al. (104) stressed the importance of continuous measurements to make sure the targeted outcomes are not derailed. Similar suggestions were made by Thompson (105) when using video games to improve the health behaviors of patients with Type II diabetes. Thompson emphasized that it is ideal for embedding the evaluation in the game if possible.

Video games can become problematic if the individual has difficulties managing other life activites. Literature has continuously emphasized the importance of close supervision to ensure the playing experience is healthy and productive (106, 107). In addition, the focus of supervision should extend beyond just playing time, frequency, and the content of video games. It is also equally important to monitor with whom the individual plays games. The effect of the company is bi-directional. For example, Osmanovic and Pecchioni (108) illustrated that video games can improve family relationships and connections when played with family members. On the other hand, when playing online video games with strangers, cyberbullying and cyber-victimization could happen (109, 110).

Resources

In this last section, we share useful resources (see Table 2) for those interested in leveraging video games in their work with people with disabilities. Specifically, these websites and information provide detailed ideas of encouraging healthy video game habits and showcase real-life examples of how accommodations can be implemented in video games. We hope it will serve as a start and spark more discussions on this important but overlooked topic.

TABLE 2 Video game resource.

Resource	Website	Description
Ablegamers charity	https://ablegamers.org/	A community that provides resources for individuals with disabilities to engage in video games. The focus is on combating social isolation by playing games. A wealth of information about gaming specific assistive technology is included on the website. In addition, the website also provides suggestions for game developers to be more inclusive when designing the game.
Ability power	http://www.abilitypowered.com/	Created by a person with a disability who found joy in playing video games. The website provides game accessibility review. The support group format of the website offers discussion on the Discord and Steam. Ability Power also has a YouTube channel that streams their video game play.
Blind gamers	https://blindgamers.com/	A self-help website specifically created for players with visual impairments. The website has a clean look and is screen reader friendly. The website provides a platform for players to rate how accessible and enjoyable the games are.
Dager system gaming enabled	https://dagersystem.com/	Founded in 2012 by a group of video game players with disabilities. The website provides reviews of game accessibility using a four-point rating system on aspects including visual, audio and fine-motor control. A database for gaming accessibility in on the way and will be available soon.
The controller project	https://thecontrollerproject.com/	The website focuses on developing accessible controller for playing video games. Besides a library showing how the controllers can be modified to be more accessible, they also accept requests from players who are interested in customizing their controllers. A YouTube channel is available to show how the controller can be modified.
International game developers association: game accessibility special interest group	https://igda-gasig.org/	A special interest group for video game accessibility under International Game Developers Association. The group provides a channel for communication between the game developers and players with disabilities. In addition, it also provides suggestions for researchers who are interested in this topic.

Conclusion

Video games stand to offer much to the field of rehabilitation. There are numerous benefits that educators, practitioners, and researchers can take advantage of to help those with disabilities. With educational purposes in mind, educators can leverage serious gaming design to teach students mathematic and spatial learning; with the potential to improve emotional regulation, practitioners can rely on video games to better serve their clients with psychological needs; with the cacpacity to promote self-determination and motivation, researchers can design more game-based intervention and gamify the intervention process. However, there are also a number of risks that should be accounted for when designing or implementing interventions that use video games. Certain disability populations may be more susceptible to the negative effects of video games. Due to the concerns, such as eccessive use of video games, some decide to completely avoid it. While we understand these concerns, we argue that with careful and stragtegic planning, video games can be a useful tool. With this in mind, users should strive to have a well-defined purpose, be aware of the risks, and note the importance of monitoring and supervision when utilizing video games with vulnerable populations.

Author contributions

HK: Conceptualization, Formal Analysis, Methodology, Resources, Writing – original draft, Writing – review & editing. MY: Conceptualizing, Resource, Writing – original draft. DR: Conceptualizing, Resource, Writing – original draft. C-CL: Conceptualizing, Writing – review and editing

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Conflict of interest

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Experiencing accessibility of historical heritage places with individuals living with visible and invisible disabilities

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Introduction: Around 16% of world's population lives with visible and invisible disabilities. People with disabilities' participation may be limited because of the environmental obstacles. Moreover, historic heritage places were built before the development of accessibility standards and the rights of people living with disabilities and the majority were not designed to be accessible. Access to historic heritage places is important for carrying out the activities in place but also to create and reinforce identity. The aim of this study was to explore the experiences of people with visible and invisible disabilities when visiting heritage sites considering accessibility issues.
Methods: This study is a qualitative interpretive description. Participants were adults with visible (e.g., motor disability) or invisible (e.g., autism) disabilities. For data collection, go along interviews (also referred to in the literature as "walking interview" in two different locations in the Historic District of Old Quebec in Quebec City were conducted. Thematic analysis was done.
Results: Twenty-one participants completed two go along interviews: one in the *Séminaire de Québec* (Seminary of Quebec City) and the other in Petit-Champlain and Place Royale areas of Quebec City. Three themes emerged: (1) Obstacles and impact on participation; (2) Disabling accessibility; and (3) Heritage meaning.
Discussion: The barriers identified by participants are diverse and differ according to the person and the type of disability. However, social and leisure activities were particularly limited, despite the strategies developed by some participants. Participants in the study demonstrated an interest in accessing to heritage places, therefore it seems essential to consider the needs of people with disabilities when developing accessibility solutions, and to seek a balance between preserving heritage and promoting inclusive and equitable access for all.

KEYWORDS

accessibility, environment, go along interview, walking interview, people with disabilities, inclusion, participation, built heritage

1 Introduction

People with disabilities currently represent around 16% of the world population (1). Both people with visible (e.g., wheelchair user) and invisible (e.g., autistic person) disabilities may experience challenges related to environmental barriers that may hinder their social participation. The concept of social participation refers to "the total accomplishment of life habits, resulting from the interaction between personal factors (impairments, disabilities and other personal characteristics) and environmental factors (facilitators and obstacles)" (2). According to the Invisible Disabilities Association, an invisible disability is a "physical, mental or neurological condition that is not visible from the outside, yet can limit or challenge a person's movements, senses, or activities" (3). The elements of the environment involved in social participation are very diverse, and participation can therefore be affected at different levels and in different spheres of the person's life.

Many people with disabilities experience accessibility problems at public spaces. This means that the person may have difficulties entering the building or may not be able to enter at all. In other situations, even if the person is able to access the building, it may not be possible for the person to complete the intended activities in that location (4). Among public spaces, historic places, which were built before the development of accessibility standards and rights for people living with disabilities are often some of the most inaccessible. As they were not designed to be accessible (5), some people with disabilities find them difficult to access and navigate (4).

According to *Canada's Historic Places,* a historic heritage place is "a structure, building, group of buildings, district, landscape, archaeological site or other place in Canada that has been formally recognized for its aesthetic, historic, scientific, cultural, social or spiritual importance or significance for past, present or future generations (heritage value)" (6). Enhancement and transmission of cultural heritage is important because it is a reflection of a society's identity (7). But also, historic heritage places have different functions associated to several categories such as residence, education, health and research, religion, community, government activities or transportation, among others (8). Since historic heritage places have various functions, many activities such as tourism and cultural leisure, education, work, participation in the political life, may be restricted for people with disabilities (9). Moreover, heritage places are usually protected, and they cannot be modified, so adaptations to make them accessible constitute a significant challenge. Therefore, historic heritage places can be particularly problematic environments for people with disabilities as they are sometimes partially accessible and usually inaccessible (10). Some examples of the most frequently reported barriers to access to these kind of places are steps at the entrance or inside the buildings, the lack of handrails, the uneven floors, the sidewalks or their absence, sound reverberation, the lack of lighting, complexity of presented information (ex.: long texts or complex language), and insufficient space in bathrooms (9, 11–15).

Although there is some literature about access to culture that takes into consideration the point of view of people with disabilities, such museum accessibility (16, 17), there are not so many studies that have been carried out in the specific field of historical heritage considering the first-person experience of people with disabilities (10, 12, 15, 18). Studies that consider the perspectives of people with disabilities in a patrimonial context usually do so through interviews or questionnaires (9, 19) or usually only involve people with physical disabilities (20, 21). Thus, the propose of this study was to explore the experiences of people with visible and invisible disabilities when visiting historic heritage places considering accessibility issues.

2 Methods

This study used a qualitative interpretative description approach (22) to understand people living with disabilities' experiences. In order to explore and describe experiences in a real context, go along interviews method in heritages places was used. This technique is usually referred to in the literature as "walking interview" (23, 24). However, in view of the differences in the mobility abilities of the study participants, the term "go along interview", will be used throughout this article. This term, already used in some studies (25), is less ableist and focuses on the characteristics of the interview rather than on the individual characteristics and functioning. Research team members come from a variety of backgrounds and disciplines, such as occupational therapy, architecture, design, sociology, and engineering, including accessibility and heritage experts. A multidisciplinary team enables the combination of knowledge from different fields, which is essential for the study of accessibility of historic heritage places and the development of research studies adapted to the needs of the context (26, 27).

2.1 Participants and recruitment

Participants were adults with disabilities responding to the following selection criteria: (1) to live with a visible (motor, visual, normal aging process related) or invisible disability (autism, intellectual disability, hearing disability, chronic pain or fatigue); (2) to be 18 or older; (3) to be able to communicate with the research team with or without aids or support; (4) to be able to get to and navigate in the Old Québec (Vieux-Québec) Historic District, in City of Quebec (Canada), with or without mobility aids. Although people with invisible disabilities may sometimes have certain traits that are recognizable to others, they often go unnoticed in casual interactions. However, their quality of life and functionality can be as much affected as for people with more obvious disabilities (28). People with invisible disabilities "needs cannot be accommodated simply by making "obvious" physical alterations in the structures of ingress and egress, but only by making more sweeping changes in the environment" (28). For this reason, it is essential to include this population in the study.Snowball and convenience sampling was

carried out (29). A recruitment poster including a description of the study and the interview process, as well as eligibility criteria, was distributed to various Facebook groups of people with disabilities. Several organizations related to the targeted disabilities (e.g., *Regroupement d'Organismes de Personnes Handicapées de la region 03* - ROP 03; Kéroul, Bureau des étudiantes en situation de handicap de l'Université Laval) participated to the recruitment process. Some participants from the researchers' participant databases were also contacted to complete the recruitment to ensure the participation of people with all sorts of disabilities. Participants who had expressed an interest in taking part of the study were contacted by telephone or e-mail to determine if they were eligible and to explain the project and their participation. No diagnostic documents were required to participate, the person self-identified as living with a disability.

2.2 Data collection

For the data collection, the team members conducted go along interviews (23, 24) in the Historic District of Old Quebec in Quebec City, included in the UNESCO World Heritage List since 1985 (30). This technique consists of on-site interviews, in which participants can explain their experiences in relation to a specific environment while visiting the place. As person-environment interaction may be "difficult to express in simple terms" (31), it facilitates the expression of the perceptions concerning the environment thanks to the real-time and direct interaction between the person and the environment (24, 32). This method also allows researchers to perceive the attitude and behavior of the person as well as the changes of the environment.

Two historic heritage places were chosen for the go along interviews: (1) School of Architecture of Université Laval located at the *Séminaire de Québec* (Seminary of Quebec) (Figure 1) and (2) Petit-Champlain and Place Royale sectors in the Old-Québec area (Figure 2). Both places were chosen because of their heritage-related importance. *Séminaire de Québec* is a building and the other one Petit-Champlain and Place Royale sectors are exterior sites, so both, indoor and outdoor historic heritage places could be explored. Also, both places allow participants to visit them with members of our research team even if there are some environmental barriers. *Séminaire de Québec* has some adaptations which allow people with mobility impairments' circulation in most of the floors, such an elevator and two lifts, and some adapted toilets, which does not mean they were completely accessible. The itinerary in Petit-Champlain and Place Royale sectors did not include adaptations, but circulation on certain streets was possible for participants. The itineraries were predefined in order to ensure the safety and comfort of the participants as well as the study of environments presenting heritage characteristics. Two or three members of the research team, with no relationship established with participants prior to study, were present during the go along interviews. One of them led the interview and guided the participant orally (a sign language interpreter was provided for the interviews with a deaf person), and the others checked technical elements (e.g., microphones, recorder, and camera) and managed contextual issues (e.g., taking the library's key when it was closed). All participants had to complete two go along interviews, one on each site, and this was done between April and August 2022 during daytime or evening to cover different environmental situations along with different weather conditions. Some Covid-19 travel measures, such as proof of vaccination, were still in place during the data collection period. Participants had to describe their experiences in both places and asked some open questions based in a semi-structured interview guide. Interviews were both filmed and recorded for subsequent transcription and analysis.

2.3 Data analysis

Every go along interview was integrally transcribed by a team member, and the transcripts were revised by the first author to ensure accurate transcription (ARR). Videos were used to contextualize audio data when necessary (24). Two cycles of analysis were carried out. First, coding (33, 34) was conducted to structure the data and guide subsequent analyses. A codebook which was prior developed was used and it was based on two sources: (a) the Human Development Model—Disability Creation Process (HDM-DCP) (35, 36), and (b) on some elements of the Rick Hansen Foundation Accessibility Certification (RHFAC) survey (37). The codes referred to the person, the social and physical environment, and the activities and roles. HDM-DCP Model provides a perspective on the interaction between the person and the environment. The Rick Hansen Foundation Accessibility Certification (RHFAC) survey provides a structure for addressing potential physical environmental obstacles. Five members of the research team participated in the coding process (ARR, MLa, JR, MLe, AS). Each research team member involved in the coding process individually coded the same two complete interview transcripts (one outdoor interview and one indoor interview). Then the team members carried out two team meetings in order to homogenize and calibrate the understanding of each code as well as the criteria in the choice of codes. After this coding validation process, every interview transcript was coded by one person of the team and revised by another team member. All coding was performed on NVivo version 13 (38). Secondly, once the first coding was complete, theming the data analysis (34) was carried out to identify participants' experiences. Then, similarities and differences among the emerging elements have been explored and discussed within the team in order to identify and organizing themes and sub-themes. To minimize bias possibilities, the research team carried out discussion sessions throughout the entire analysis process.

2.4 Ethics

The study was approved by the sectorial ethics committee on research in rehabilitation and social integration of the *Centre intégré universitaire de santé et de services sociaux de la Capitale-Nationale* (#2022-2422) and every participant signed a consent form.

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FIGURE 1
Séminaire de Québec.

3 Findings

Twenty-one individuals participated to this study and each one completed two go along interviews, one at the *Séminaire de Québec* and one at Petit-Champlain and Place Royale sectors, for a total of 42 go along interviews. Most participants were not familiar with the *Séminaire de Québec*, although some had already visited the Petit-Champlain and Place Royale areas. Regarding participants'

FIGURE 2
Petit-Champlain and Place Royale sectors.

characteristics, 57.1% ($n = 12$) of the participants were women, 38.1% ($n = 8$) were man and 9.5% ($n = 2$) was nonbinary people and the ages of the participants ranged from 22 to 79 years old (median = 40). Participants had different disabilities and different functional profiles, 52.4% ($n = 11$) live with a visible disability and 47.6% ($n = 10$) with an invisible disability. Most participants had co-morbidities, meaning that they also had other types of disability, often milder than the main one. All the participants who used assistance devices were familiar with them, except for one who had recently obtained her mobility device (walker).

TABLE 1 Participants' characteristics ($n = 21$).

Age	*n*	%
22–35	7	33.3
36–50	3	14.3
51–64	4	19.0
65–79	5	23.8
Did not provide age	2	9.5
Gender*		
Woman	12	54,5
Man	8	36.4
Non-binary	2	9.1
Main disability		
Mobility	4	19.0
Vision	4	19.0
Hearing	2	9.5
Autism	4	19.0
Intellectual	1	4.8
Pain	2	9.5
Aging-related	4	19.0
Comorbidities		
Yes	14	66.7
No	7	33.3
Limitation frequency		
Everyday	13	61.9
Several times a week	2	9.5
Several times a month	1	4.8
Several times a year	2	9.5
Never	0	0
Did not provide limitation frequency	3	14.3

*$n = 22$ for this characteristic: a person has indicated that she was both a woman and non-binary.

Concerning perceived limitations, most participants felt limited by environmental barriers daily, but the perception of the frequency of limitations was heterogeneous within participants (see Table 1 for detailed participants' characteristics and Table 2 for assistive devices and support information). The go along interviews lasted between 27 and 125 min. Every participant finished the interview at the *Séminaire de Québec* and only one of the participants could not finish the interview at Petit-Champlain and Place Royale sectors due to the pain while navigating the uneven pavement (the interview lasted 8 min).

TABLE 2 Assistive devices and support.

Main disability	Assistive device or support
Mobility ($n = 4$)	Manual wheelchair ($n = 2$)
	Motor wheelchair ($n = 1$)
	Walker ($n = 1$)
Vision ($n = 4$)	Dog ($n = 1$)
	White cane ($n = 2$)
	None ($n = 1$)
Hearing ($n = 2$)	Interpreter ($n = 1$)
	Cochlear implant ($n = 1$)
Autism ($n = 4$)	Dog ($n = 1$)
	None ($n = 3$)
Intellectual ($n = 1$)	None ($n = 1$)
Pain ($n = 2$)	Motor wheelchair ($n = 1$)
	None ($n = 1$)
Aging-related ($n = 4$)	None ($n = 4$)

The three themes that emerged from the data analysis were: (1) Obstacles and impact on participation: which addresses the obstacles encountered by participants during the go along interviews, their impact on participation, the strategies developed by participants, as well as the roles of other individuals present on the site; (2) Disabling accessibility: which includes some of the partial accessibility solutions already present on sites, and the feelings experienced by participants towards these solutions, and (3) Heritage meaning: addressing the meaning and importance of historic heritage for people with disabilities. Citations are meant to identify the number of participant, gender initial, and condition (e.g., autism, mobility, etc.).

3.1 Obstacles and impact on participation

Most participants had already visited Old Quebec simply to walk around and enjoy the atmosphere, for cultural activities or events (e.g., workshops, shows, carnival, theater) or to go to local restaurants and bars. However, they explained how their participation in these activities could be hindered by obstacles such as uneven ground, sidewalk obstructions (e.g., shop displays, other posters, garbage cans) or the lack of rest areas and street furniture. A participant mentioned: "That [pavement] is something I hate in my life. I don't like it (…) But you can't change it. There are a lot of cities like that in the world" (P07M-Mobility).

Other factors that could limit participants' activities would be echoes, too many sensory stimuli or crowded conditions. Echo, a characteristic feature of heritage buildings, was mentioned by several participants with different disabilities as an obstacle. Notably autistic people and those with hearing impairments, but also participants with visual disabilities or chronic pain considered it to be disruptive or distracting, and a significant barrier to communication. A participant said:

> When there's an echo, it's hard for me to understand. The voices seem to blend together, and it's hard for me to situate myself. And I can only hear on one side, so I can't localize the sounds. I have the impression that the sounds are coming from everywhere. (P15W-Hearing)

Concerning sensory stimuli, in particular, participants with autism mentioned that there were too many sensory stimuli, especially on the outdoor course and in terms of visual and acoustic stimuli. The variety of colors, shapes, and textures, as well as noise and music, were elements that could make a visit to Vieux-Québec uncomfortable for some of the participants. One participant explained: "So, it is a lot… (…) It's like: o.k. There's a lot of smells, there's a lot of people, there's a lot of noise" (P18W-Autism). In terms of crowds, since Petit-Champlain and Place Royale are tourist areas, large groups of people on site were disruptive for many participants. For example, a participant reported that a group around a street musician could be disturbing for deaf people because they might have difficulty

understanding the situation as they don't perceive the sound information. But also, for autistic people who could feel overload. Concerning shows and cultural events, one participant mentioned that these were not always adapted to the deaf community and suggested varying the types of events and including deaf-friendly activities such as mimes:

> The square is open, so I can see everything. Sometimes, when there's a show, people gather around. But we can't hear. There might be people laughing. There's a joke … Sometimes there are little gatherings like that in the summer, eh? Little performances. We don't hear them, so we look to see if there's ever any action, like, more, mimes, or uh … That would be interesting, we'd be more likely to stay, at least, to enjoy the activity. (P16W-Hearing)

Access to toilets was often raised as a potentially problematic feature. Several participants, with different disabilities, explained that this would be one of the first things they would like to spot when visiting a new location. However, some participants said they avoided going to public toilets for various reasons (e.g., lack of cleanliness, toilets only partially accessible). One participant even mentioned that some people with disabilities will resist drinking before going to a place where they are not guaranteed easy access to toilets: "When I get home, I drink two or three glasses of water, I'm thirsty because we try to avoid drinking. (…) Because it's a bit annoying to always be looking for an accessible bathroom" (P06W-Mobility). Additionally, access to shops and restaurants was often limited, for instance due to steps or an inaccessible entrance, lack of toilet facilities on the floor and difficulties in communicating with staff.

To compensate for these obstacles, the majority of participants explained the strategies they had consciously or unconsciously developed alternatively.

3.1.1 Participants' strategies

Many different strategies, depending on the person and the type of disability, were mentioned by participants. Many participants mentioned having to plan their activities in advance to ensure that environmental conditions would allow them to carry out the activities once on site. To do this, some participants explained that they consulted the city or district website, as well as pages or groups of people with disabilities on digital social networks. A participant mentioned:

> The planning process … I'd go on the Internet, on the Quebec City website, uh, and then I'd go to the … the neighborhoods or the districts of the city. I'd go to the Petit-Champlain district, then I'd look at what's there, stores, and restaurants. There are stairs to the top. There's the château at the top. So, I'd look at the little attractions around it. (P12W-Intellectual)

Regarding the excess of stimuli, autistic participants also mentioned several strategies such as using earplugs, focusing only on one element of the environment ("tunnel vision"), favoring already familiar places, avoiding busier areas, and settling in quiet places (e.g., rest area) to reduce the presence of stimuli. A participant noted:

> You know, it doesn't take much, it doesn't take a room, an isolation room, necessarily … But a corner, you know, somewhere. (…) I would sit down, put on my earplugs so I can't hear anything, and wait for it to pass, you know. Because … there's a lot of people there, because there's noise, because there's … You know, there's a lot of things there. (P18W-Autism)

Several communication strategies were mentioned. On one side, some participants consulted maps on their cell phones, or read text (in the case of people with visual disabilities) by taking a photo and using the "VoiceOver" option, which provides descriptions and screen-reading. On the other side, using paper and pencil to communicate when needed was the strategy used by the deaf person. For carrying out activities, she mentioned that she had to engage in group activities and hire a sign language interpreter out of their own money, since leisure activities are not considered essential (unlike medical appointments, for example, where the interpreting service would be provided): "We'd already booked a glassblowing workshop, glass that we heat. Then we had booked an interpreter, to go to the workshop that we had booked to come here, in town" (P16W-Hearing).

In addition, when signs or directions were unclear or it was difficult to find one's way around, participants had two choices: make additional trips or ask for help. Some participants explained that they would often avoid interactions with other people, particularly requests for help, and would therefore prefer to find solutions on their own.

> Well, one of the reasons I like having a map like this is that I don't have to ask people around me. (…) It's harder for me to go looking for information, to ask "hey, where's that store?" I like having the map so I can find my way around without having to communicate with someone I don't know. (P15W-Hearing)

However, as navigating was often difficult for participants in this type of environment, some people mentioned that they will, sometimes in spite of themselves, ask for help from people present on the premises to avoid moving around more than necessary.

3.1.2 People, a facilitator or a barrier?

Heritage places are often tourist or busy places, and the presence of other people would seem to have an impact on participation for many participants. While some noted that contact with other people was positive for them, many of our participants mentioned that crowds could become an obstacle for various reasons. Participants with different types of visible and invisible disabilities (wheelchair users and other mobility aids, people with autism, people with intellectual disabilities, people with age-related disabilities, visual disabilities, and hearing disabilities), mentioned problems, obstacles, or discomforts in this regard. For example, some people with different disabilities

(e.g., hearing, mobility, autism), mentioned that crowds could easily block circulation or make communication difficult: "That's for sure, because it's harder for me to understand [other people] when there are a lot of people around me. But I like it too, in a way, because it makes things animated, you know, it makes … It adds life" (P15W-Hearing). Participants who had an assistance dog also mentioned that other people and other dogs might tend to interact with theirs. Others mentioned that they felt stressed in crowds or would have feared getting lost if they had found themselves alone in a crowd. As one participant pointed out: "The biggest obstacle? The biggest obstacle … Uh … Not getting lost in the crowd when there's a lot of people around" (P12W-Intellectual). In addition, some participants explained that they would appreciate the presence of quiet rest areas. However, several participants mentioned that the people around them did not represent an obstacle for them, at least with the level of crowds existing during the go along interviews.

In several situations during the go along interviews, and according to anecdotes shared by some participants, they perceived that individuals without disabilities would be more aware of accessibility issues than in the past. One participant shared a situation she and a group of deaf people had experienced in a restaurant in the Petit-Champlain district:

> We were able to order, um … Of course, sometimes you don't understand, you know, you try to read lips. Then finally, with the printed text, it worked … We put our thumbs up. We said: "Yes, that's good". The waitress at the table was open-minded. (P16W-Hearing)

Nevertheless, some participants mentioned that they felt more at ease when they were accompanied around historic heritage sites, which they felt was more relevant on a first visit, especially if they have a visual impairment. Others said that being accompanied made their orientation easier, or reduced their stress levels: "Right now, yeah, I feel … good …. I feel well accompanied. Being on my own, I don't know (…) I'd be able to do it on my own, but I'd be more stressed" (P21M-Autism). Despite this, most participants expressed their interest in being able to enjoy historic heritage places completely by themselves, which could be encouraged with the implementation of accessibility solutions.

3.2 Disabling accessibility

In historic heritage places, some of the major obstacles identified by participants were characteristic features of the historic environment, such as irregular pavement, heavy doors, echoes in indoor settings, complexity of the building's structure or the presence of steps at building entrances. Accessibility solutions are sometimes available to counter these obstacles, but they do not always enable complete autonomy. An example of this type of solution would be those requiring interaction with another person or the presence of an assistant or another person (e.g., platform lifts requiring a member of staff to activate it with a key, or removable ramps). Confronted with this kind of solution, one of the participants commented: "It's just really *ableist*, as they say. To say, like, we can't go out unless we're accompanied with another person. If we don't have anyone, we stay home (…) It's a bit insulting" (P13W-Pain). In a normal situation, such a situation could have led to feelings of insecurity or to concrete situations of discomfort or risk for people with disabilities.

3.2.1 Comfort and safety

People with disabilities seem to sometimes experience situations of physical or social discomfort, as well as feelings of insecurity or risk situations. For example, with regard to feelings of insecurity, two participating women mentioned that they wouldn't necessarily feel safe if they did the route alone and at night (P06W-Mobility, P12W-Intelectual). This feeling of insecurity was more related to her gender than to her disability. In terms of discomfort, access through secondary doors—often the only adapted ones—would be socially and dignity-disturbing for people with mobility disabilities. Another uncomfortable situation would have been to wait for the physical environment to be adapted for access, for example due to the installation of an accessibility solution or simply the opening of a double door to make the space wider. This can also make the person feel observed by others in the area. For example. during one go along interview, the participant was trying to access a business whose manager explained that the second door could be opened. The participant mentioned that she felt like she was in the spotlight at that time (P06W-Mobility).

In terms of safety and physical comfort, elements such as the pavement, the slope of the ground or poorly-maintained sidewalks can make navigating very uncomfortable or even unsafe for the person. These circumstances led one participant, who uses a wheelchair and lives with chronic pain, to stop her outdoor go along interview. Other participants with the same type of disability (chronic pain) also expressed discomfort when moving around on this kind of surfaces: "Especially as the floor isn't, uh, it's not super smooth, there are cracks. So sometimes, you know, if you don't have very strong ankles or good balance, it would be easy to get stuck" (P09W-Pain).

Despite the difficulties experienced during the go along interviews, and the lack of accessibility of the heritage sectors visited, participants expressed their interest in heritage and highlighted the significance these places had for them.

3.3 Heritage meaning

Most participants, regardless of their type of disability, associated heritage with history, beginnings or origins, "what the ancestors left behind" (P02M-Visual), but also with culture and a socio-political context. Some participants saw heritage as a source of baggage and reference points for society: "So it's a document that's very faithful (…) And it reflects where we come from. If you know where you come from, there's a good chance you know where you're going" (P11M-Aging-related).

In addition to emphasizing the beauty of the sites, participants perceived historic heritage places as special places with character

and a soul, which are important to experience. Often, participants associated the places with the most historic heritage features with a pleasant, warm atmosphere. For example, one autistic participant described the library he visited in the *Séminaire de Québec* as a warm and comforting place:

> Do you know that my comrades are likely to end up here? You know, I feel like I'm describing a different kind of animal, but people who are hyper-sensitive or have disorders like that, not just ASD, we like quiet places. And here, it's like a comforting place, where I would tend to come back often (…) I get dizzy imagining all the treasures that are hidden behind the doors, just waiting to be discovered. (P14M-Autism)

Participants described their understanding of heritage and how important it was to them. Despite accessibility issues, all participants showed an interest in heritage and especially in the possibility of accessing it, even if some did not identify themselves as regular museum visitors or as having a great interest in history: "Heritage? Yes, well, I'm not a big fan of museums, but still, I think it's important. Yes, it's important to go and see things from the past, it helps you see how things used to be" (P2M-Visual). Another participant said:

> I recognize how important it is, but for now it's a statement, not a life's habit. I like it when I'm invited to a museum. On my own initiative, I don't go (…) I say to myself: "Starting next month, I'm going to start going to the theater, and museums" every time I go, I'm transformed (…) like, "Wow, this has deepened my understanding of the land of my ancestors". (P14M-Autism)

3.3.1 Balance between accessibility and heritage

The majority of participants, with different kinds of disabilities, perceived historic heritage places as not often accessible, and many, especially those with mobility disabilities or chronic pain, spontaneously mentioned inaccessibility in their own definition of heritage. For example:

> It's the history of course, but not accessible [laughs]. That's for sure. Then there's the complexity of making it accessible, given the heritage regulations. You can't do that, it has to be with the same materials. You know, you can't just do whatever you want, but I think … there's certainly a way of doing something. (P06W-Mobility)

Most participants apprehended that the sites they visited had not been built with accessibility in mind, and the complexity of adapting them. They were in favor of heritage preservation, but appreciated the sites and felt that everyone should have access to historic sites, regardless of their condition. For example, one wheelchair-user participant mentioned:

> When they (historic sites) were built, they weren't adapted for people in wheelchairs. So I always think about that. But yes, a historic site, should be, uh (hesitation), should still have access to everyone. Even for people in a wheelchair. (P07M-Mobility)

Although some participants were open to partial access to heritage buildings and sites, or to alternative solutions, they preferred to have physical access to the integrity of the site: "unless we visit it virtually. But it's fun to be in person…" (P06W-Mobility).

In short, despite recognizing the importance of preserving heritage for its historical and cultural value, participants categorically expressed their interest in accessing and enjoying it.

4 Discussion

The purpose of this study was to explore the experiences of people with visible and invisible disabilities when visiting historic heritage sites considering accessibility issues. Most of the studies about public building accessibility do not included participants in the accessibility evaluation (39). The use of go along interviews for data collection represents a suitable method in the field of accessibility and has enabled us to obtain the perspective of the main people concerned by accessibility problems (25). Furthermore, working in this way with the people directly concerned in a real-life context encourages the creation of realistic solutions in the future (40, 41).

The content of the three themes—obstacles and impact on participation, disabling accessibility and heritage meaning—provided a portrait of the elements that have an impact on people with disabilities in a heritage context, as well as the meaning and importance of built heritage for people with disabilities. The obstacles identified by the participants are very varied in nature and intensity and differ according to the individual and the type of disability. This may be related to the heterogeneity of the study sample, which included people of different ages and genders, with various disabilities and levels of autonomy. However, there were some elements that appeared to be problematic for the majority of participants, regardless of disability type and other participant characteristics. Many of these barriers correspond with what is already known from the literature, such as uneven flooring (pavement), steps, particularly at shop entrances (9, 12, 13, 18), as well as objects on sidewalks (9, 19) and the lack of accessible toilets (13, 42). However, some participants ignored some obstacles that were obvious for the research team, such as access to certain shops or restaurants with steps at the entrance. One possible explanation of this reaction could be a coping or acceptance strategy related with the adaptation to the disability (43) in order to avoid continuous confrontation with environmental barriers It is worth noting that commercial and restaurant buildings were not originally designed as public spaces. For the most part, they were conceived as residential buildings.

The presence of many people was also central to the results of the study. Heritage places contribute to the tourist appeal of cities. When historic districts become tourist attractions, they are often crowded. These areas may not necessarily have been designed or

adapted to receive a large number of visitors. This can contribute to large groups of people being an obstacle to circulation, for example. It should also be pointed out that even if the most restrictive measures of the Covid-19 pandemic has ended when the data collection began, some travel measures were still in force (e.g., vaccination proof at boarders). This could have resulted in some interviews, particularly the first ones, being conducted in a less busy context than usual. Other measures, such as mask wearing, changed or disappeared during de data collection period. Concerning the School of Architecture, located in the *Séminaire de Québec*, it also less busy than usual, particularly during the last interviews, due to students' summer vacations. It may mean that the volume of visitors and students could be perceived as less of an obstacle for some participants in the study.

Some of the obstacles mentioned by study participants have received less attention in the literature. For example, none of the articles in the reviewed literature addressed the issue of excessive stimuli in historic heritage places. These elements would seem to have a closer link with invisible disabilities (e.g., autism) than with visible disabilities (e.g., motor disabilities). However, elements such as noise or visually charged environments, which were mentioned by participants as sometimes problematic in historic heritage contexts, were also considered obstacles in other contexts (44, 45). In addition, in line with what the study participants said about heritage contexts, the presence of rest areas—quiet places where there are few sensory stimuli—would be also particularly appreciated by people with autism in other contexts, such as home or school (46, 47).

A variety of obstacles were mentioned by participants. Indeed, many elements of the physical environment were problematic, and this may be due to the characteristics and materials of the historic buildings (5). However, other obstacles were mentioned by participants, such as the presence of many people, the complexity of the buildings or sensory overload. Barrier-free design originally referred to access for wheelchair users (48). However, today, following the evolution of this field and related concepts, "universal design is a process that enables and empowers a diverse population by improving human performance, health and wellness, and social participation" (49) and accessibility aims "to ensure to persons with disabilities access, on an equal basis with others, to the physical environment, to transportation, to information and communications, including information and communications technologies and systems, and toother facilities and services open or provided to the public" (50). Both the finding of this study and current concepts of accessibility transcend barriers in the physical environment, which mainly affect people with mobility impairments and it should be taken into consideration when developing recommendations and accessibility solutions [e.g., tactile signage or auditive information could improve accessibility of historic heritage places (51)]. Participants mentioned several activities that could be limited for them in the studied areas and buildings of Old Quebec. The majority of these activities were leisure activities (e.g., going to a bar or restaurant, attending a show). According to the MDH-PPH, leisure activities are "habits related to recreational or other activities, carried out during free time in a context of pleasure and freedom" (2). According to this model, leisure includes, among other things, socio-recreational activities (e.g., going to a bar, sightseeing or visiting relatives) and also arts and culture (2). People with disabilities could therefore experience a disabling situation in certain leisure-related activities if historic heritage places are not accessible. Social relationships, sometimes cultivated during leisure activities, could also be limited.

Most participants described strategies they use to cope with the difficulties they encounter, which could enable them to counter certain obstacles. However, their strategies were not always sufficient to successfully complete activities. The results obtained with regard to limited activities are more pronounced in the go along interviews on in the Petit-Champlain and Place Royale sectors than in the *Séminaire de Québec*. Two factors could have an impact. First, the fact that the architecture school was not busy, and that some services were not available due to school vacations, could limit the possible interactions between participants and the environment. Secondly, the participants recruited were not necessarily students and might feel less identified with the environment explored at the *Séminaire de Québec*. However, the Petit-Champlain and Places Royale areas of Old Quebec were familiar to most participants and included spaces where they would like to carry out activities in a real-life context.

Regarding the accessibility solutions already present in the sites visited during the go along interviews, some seem to limit the autonomy of people with disabilities. The implementation of poorly adapted solutions may be due to a lack of awareness or resources among decision-makers (52, 53) and designers (54), as well as to current accessibility standards, which are often limited and lack a holistic approach, considering all the dimensions and needs of people with disabilities. Another factor that may influence the use of solutions that do not fully meet the needs of the people concerned could be the limitations on modifying heritage sites due to conservation laws (7). These partial solutions, while they may be useful for some people, could contribute to segregation and a feeling of exclusion among people with disabilities. As a result, people with disabilities may even avoid visiting heritage sites.

Heritage places often have historical, cultural or social significance (6) and reflect the identity of a culture (7). Lack of access to these places is likely to encourage a lack of access to cultural elements essential to the development of a socio-cultural identity among local residents. For example, according to Newman and McLean (55), lack of access to museums, often key sites for heritage and culture, could have an impact on identity development, with loss of identity concomitant with social exclusion (56). In the province of Quebec, Canada, heritage places represent a key element for the local cultural identity of the population living there. However, if an area is not accessible, this could also have an impact on tourists and their understanding of local history (57). Heritage preservation is therefore important for the development and maintenance of social identity. However, social and architectural environmental factors in heritage contexts can have an impact on the social roles of people with disabilities, such as access to culture and

socio-recreational activities. This could also have an impact on this population's sense of identity and wellbeing. As Vardia et al. (58) have already documented, the balance between accessibility and conservation of the place and its ambience is fundamental. It is therefore essential to consider the needs of people with disabilities, who could also benefit from the cultural richness that heritage places can provide, and so promote the evolution of socio-cultural identity.

Given the importance of heritage sites and buildings in the lives and identities of citizens, it is necessary to think about the possibility of making compromises with respect to the physical environment, but also to the social environment. In addition to architectural solutions that can be installed in the physical environment of heritage sites, other elements should be reviewed in order to improve site accessibility. It would be relevant to review and rethink some of the norms of preservation of historic heritage places in order to make accessibility interventions that respond to a greater number of disabilities. Alternatively, the human environment could partially compensate for the lack of accessibility to some extent, as happens in other places, for example,some assistance services are usually provided in airports and train stations to improve the experience of people living with disabilities. It would be important to provide services that can provide support when possible architectural accessibility is not sufficient. For example, awareness campaigns and training, taking advantage of the willingness of people who are willing to help, and providing an official framework in which better services can be offered and not only depend on the good intentions of the individuals.

4.1 Strengths and limitations

The methods used in this study allows us to identify several strengths regarding its trustworthiness (29, 59). Prolonged engagement in the field and the combination of participant discourse and persistent observation during data collection, as well as team discussion and the involvement of several team members in the analyses, promote the credibility and dependability of the study (59). Preliminary findings of this study were presented to some of the participants in a co-design group as part of a subsequent stage of the study as a member checking strategy. Although the aim of the study is not to generalize the results obtained, the heterogeneous sample, including people with different characteristics regarding age, gender, and type of disability, as well as the description of the sample and context included in the article, favors the transferability of the results (59). This study also has some limitations related to the context and the methodology. First, due to difficulties in recruiting this population, only one person with an intellectual disability participated in the study, so the similarities and differences within the same population could not be explored. Then, go along interview method, particularly when used with people with disabilities, may involve some additional limitations. For example, even if the level of autonomy was not explicitly considered in the participant selection criteria and was not assessed, participants must have a relatively high level of autonomy, as the method required them to be able to navigate on a real context and communicate simultaneously. It may explain the participants' ability to develop their own strategies. Other accessibility issues might have emerged with a less autonomous sample. Although the locations were partially accessible, the itineraries were predefined, and little freedom was offered to the participants in their choices of itinerary to avoid possible safety issues and frustration that participants might experience in environments with too many obstacles. Also, predefine itineraries ensure exploration of the features of the heritage environment. Two elements could have an influence on participants' responses regarding their interest in heritage: firstly, the use of convenience sampling could have favored participation by people with a greater interest in heritage. Secondly, the data collection method used could have contributed to a desirability bias in this regard. However, desirability bias is more frequent in the study of sensitive or controversial issues and seems less likely in this study on the basis of the participants' statements. It is difficult to assess (or self-assess) interest in spaces where access is restricted to the individual, and the most salient element in this respect is the interest and right to have access to these places, independently of the interest the individual may have in history and heritage. Finally, as Ripat and colleagues (60) and Morales and colleagues (61) have shown previously, there are accessibility issues specific to winter, and others can be amplified by weather elements such as snow. However, to ensure the comfort and safety of our participants, team members decided to conduct all the go along interviews in spring and summer.

5 Conclusion

Access to historic heritage places remains difficult for people with disabilities, and they often encounter obstacles in the physical and social environment in this context. Sometimes, the strategies developed by people with disabilities to compensate for environmental obstacles enable them to access and carry out some activities, often in part. However, they often find themselves in situations of discomfort or risk. This can lead to inequalities in access to culture and to public spaces whose functions ensure certain fundamental rights, contributing to issues of equity for people with disabilities. The inaccessibility of heritage places and obstacles in the environment can have an impact on social participation, limiting access to culture and the fulfillment of certain activities, particularly those related to leisure and relationships with other people. Although people with disabilities often perceive historic heritage sites as inaccessible and the interest in history and culture is difficult to know because the access is limited for them, they are interested in accessing them. The development of accessibility solutions that meet the real needs of people with visible and invisible disabilities is therefore essential to fully enjoy heritage contexts, and to reduce the inequalities experienced by this population. In further research, detailed information on environmental barriers and facilitators

will be reported. In addition, the results of this study will serve to co-create (41) accessibility solutions for historic heritage sites, where experiential and theoretical experts will be involved to develop realistic solutions that meet the needs of all stakeholders.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Sectorial ethics committee on research in rehabilitation and social integration of the Centre intégré universitaire de santé et de services sociaux de la Capitale-Nationale. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

AR-R: Writing – original draft, Writing – review & editing. EM: Writing – original draft, Writing – review & editing. ML: Writing – original draft, Writing – review & editing. JR: Writing – original draft, Writing – review & editing. ML: Writing – original draft, Writing – review & editing. AS: Writing – original draft, Writing – review & editing. SM: Writing – original draft, Writing – review & editing. IF: Writing – original draft, Writing – review & editing. FR: Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Development of the Standardized Navigation Of Winter Mobility & Accessibility Network (SNOWMAN) course

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Introduction: Manual wheelchairs (MWC) users have limited mobility during winter months as they encounter many environmental barriers that restrict their community participation. This paper outlines the creation and standardization of an outdoor environment designed to simulate the real-life conditions and obstacles experienced by MWC users in winter.
Methods and results: This study consisted of four phases. In Phase 1, researchers used a qualitative ethnographic approach to document the specific challenges and adaptive strategies used by MWC users in winter conditions. In Phase 2, key informants with expertise in MWC winter mobility were invited to co-design the Standardized Navigation Of Winter Mobility & Accessibility Network (SNOWMAN) course. Participants reviewed draft design solutions and offered their input and suggestions to expand upon the initial design. A second co-design workshop included additional key informants, including service providers, policymakers, and professionals with expertise in landscape architecture and engineering, to validate the design solution. The workshops resulted in a detailed illustration of the SNOWMAN course, including five sections: platforms with side slopes, a miniature ice rink, curbs and curb cuts, a path with uneven winter surfaces, and modular ramps at various slopes. Phases 3 and 4 marked the conclusion of the study and involved fabrication of the SNOWMAN course and establishment of a standardized protocol for course setup and maintenance.
Discussion: The project aimed to offer several additional potential benefits, supported by the various stakeholders across the study phases, that extend beyond creation of a controlled and safe environment for wheelchair users to develop their winter mobility skills. Practicing wheelchair skills in this area may assist wheelchair users in gaining confidence which may ultimately translate to increased participation in the community.

KEYWORDS
cold climate, winter, wheelchair, rehabilitation, co-design

1 Introduction

Individuals who use manual wheelchairs (MWC) as their primary means of mobility typically experience seasonal-related accessibility barriers in the winter months (1). Environmental barriers such as icy or snow-covered surfaces and snow windrows have been reported as frequent barriers to mobility in studies of MWC users in Manitoba (2, 3). During the winter season, individuals often decrease their outdoor activities and

community engagement; however, MWC users face unique obstacles that are not experienced by individuals without disabilities, which further impede their ability to go out during the winter months (4, 5). These seasonal barriers can influence both the frequency and quality of community participation. Findings from a 12-month longitudinal study of 11 wheelchair users confirmed they made fewer trips per day and wheeled shorter distances at slower speeds during non-summer (vs. summer) months, on winter days with (vs. without) snow accumulation, and on winter days when temperatures were below (vs. above) 0°C (1). A focus group with eight Manitobans who use wheelchairs concluded that winter community participation should be considered a right for all citizens (6). Taken together, this body of research provides evidence that inclement winter-related barriers have detrimental effects on community participation among individuals who use an MWC.

According to available data, there is an estimated 288,800 individuals in Canada who use a wheelchair or scooter for community mobility. Among these users, nearly 70% have a MWC, while approximately 15% own a power wheelchair (7). Given the high prevalence of use and more adverse impact of weather conditions and terrain, the effects of winter on MWC users is particularly relevant for investigation. Observations and recounting by MWC users have identified a variety of factors that contribute to the challenges of using a MWC in winter conditions. Ice or hard-packed snow on travel surfaces causes traction loss and slippage for both the larger rear drive wheels and the smaller front casters (1, 6, 8, 9). This loss of traction can impede forward movement or create an undesired direction change due to asynchronous wheel rotation (1). The presence of cross slopes (e.g., wheeling on a sidewalk or across a driveway) can cause the MWC to slide sideways due to gravity and reduced traction (10). These conditions require additional energy expenditure and increase the risk of collisions and tipping sideways (10). Deeper snow or snow windrows cause the small front casters to sink into the travel surface, preventing forward movement. Pushing to overcome this resistance risks tipping the MWC backward, especially when ascending or descending ramps, as maneuvering a wheelchair with raised casters (e.g., in a wheelie) makes it more susceptible to tipping (6, 8, 9). Gravity creates additional resistance when travelling on inclines and generates undesirable momentum when travelling down a slippery slope (10). Snow or slush accumulation at the lower end of the ramp (when ascending) or at the ground/ramp transition (when descending) impedes caster roll, causing sudden stop and tipping hazards (10). Unaddressed snow accumulation on level ground creates ruts that become vertical barriers to an MWC user who wants to change course (10). The user must traverse the outer margins of the ruts, which is particularly difficult with small casters, and may slide back into the rut or tip over backwards when attempting to elevate casters up and out of the rut margins (10). In summary, winter conditions reduce MWC control due to slippage, increased effort due to rolling resistance, and pose stability and safety issues.

Recommendations to enhance winter mobility for wheelchair users have focused on technology improvement (3, 5), and a few studies have delved into effective strategies and devices. Recent studies have attempted to make improvements in MWC users' experience by collating information on wheelchair mobility strategies (11) and developing protocols to make area more accessible for MWC users (12). Some research has examined experienced users navigating snow-covered ramps (8) and inexperienced users using various caster types on snow and inclines (9). However, there is a significant gap in knowledge regarding winter mobility. A scoping review by the authors found only 23 studies on winter mobility involving various mobility devices (13). A few studies of winter mobility have been conducted in simulated or controlled experimental environments (14), which lack the real-world challenges of genuine winter conditions. While useful in advancing this area of research, these settings lack the ecological validity and dynamic weather and environmental challenges of authentic winter conditions.

Currently, there is an absence of ecologically valid areas for wheelchair users to develop skills to overcome challenges faced in the winter. To address this research gap, we undertook the development of a Standardized Navigation Of Winter Mobility & Accessibility Network (SNOWMAN) course. This outdoor, winter-specific environment would incorporate a comprehensive set of conditions and obstacles/barriers commonly encountered. The intended application of the SNOWMAN course would be the development and evaluation of new devices and techniques as well as clinical interventions such as assessment and training with new and experienced mobility device users to navigate winter challenges in a safe and semi-protected, but ecologically valid, context. The purpose of this project was to conceptualize, create, and standardize use of SNOWMAN course.

2 Study design and team

This study employed four phases. Phase 1 documented and compiled specific real-world challenges MWC users encounter in the community and the adaptive strategies they employ for navigating winter conditions, using qualitative and observational data obtained via a go-along interview approach. Phase 2 used a Codesign Framework with key informants to identify and prioritize which real-world winter conditions were essential to the SNOWMAN course and then integrated them into a prototype design. In Phase 3, a prototype SNOWMAN course was fabricated. Phase 4 developed a study protocol, including the measurement of ambient weather conditions to standardize administration in subsequent studies, setup of course components, and measurement of component attributes. These phases are addressed sequentially below. The interdisciplinary research team consisted of researchers with backgrounds in occupational therapy, architecture, rehabilitation engineering, and wheelchair design and use.

3 Methods and findings

3.1 Phase 1: MWC user experiences with winter conditions

To identify the specific challenges and explore strategies that MWC users employ to negotiate winter conditions in the

community, a qualitative ethnographic or "firsthand" research method was used (15). Ethnographic methods allow researchers to act as participant-observers (15). Using a "go-along" methodology (16) researchers were able to observe and verbally engage with MWC users to capture winter wheeling experiences in an authentic, natural setting.

Four community-dwelling individuals with spinal cord injury (SCI) participated. All participants were 18 years of age or older, had used an MWC for at least two years, and were in stable health (e.g., no known cardiac conditions). Participants were recruited through an outpatient SCI clinic and a provincial SCI advocacy organization.

Each participant's MWC was instrumented with a user point-of-view GoPro^{TM} video capture device and accompanied by a research assistant. and were asked to wheel their MWC through their own immediate community for up to 30 min. Two research assistants accompanied each participant: one as a spotter to ensure safety and the other for data collection (i.e., operating a second video camera for contextual perspective and audio recording of their experiences with the winter challenges and obstacles). In situ, participants were asked to point out challenges or obstacles they encountered and then demonstrate any strategies used to address these challenges. Immediately following the go-along activity, participants were taken to an indoor environment to engage in a 60-min audio-recorded debrief session with the research assistants. The go-along video footage was shared in an episodic fashion, stopping at specific events, and asking the participant to provide a narrative of what had occurred by highlighting and describing the challenges and strategies used to navigate the community.

The audio and video recordings from the go-along and debrief activities were not transcribed verbatim but viewed and listened to several times by the researchers to facilitate data analysis. Using NVivo 10.0 qualitative analysis software to manage and link the video and audio recorded data, the challenges and strategies identified in the video recordings and later discussed in the audio recordings were coded and categorized by the investigators. Integrative analyses of participants' data resulted in the development of a table of challenge types and conditions. Data analysis proceeded in an inductive manner, with each subsequent participant's data entered into the table as it was collected. The validity and comprehensiveness of the final compilation of documented barriers and strategies were confirmed by a research team member not involved in data collection, who is an experienced MWC user. Barriers and challenges identified included ascending and descending snow and ice-covered slopes and curb cuts; traversing shallow, deep and slushy snow; navigating ruts and windrows; and traversing irregular snow-packed surfaces. This list and the video footage (for illustration purposes) were fed forward into Phase 2 to inform the co-design sessions.

3.2 Phase 2: co-design of the SNOWMAN course

To identify which specific components/obstacles were essential to include in the course, key informants with expertise in MWC winter mobility were invited to attend one of two half-day co-design sessions. Co-design refers to the act of collective creativity shared by two or more people, where the MWC user is an "expert in [their] own experience" (17). Co-design has been successfully used as a means to enhance understanding of how winter conditions affect wheelchair mobility in order to develop appropriate design solutions (18). As a guiding principle that everyone has a high creative potential and ideas on how to improve their situation, we sought diverse points of view regarding a common experience. We used an established four-step co-design framework (19), addressing the first three steps (conception of the design solution; validation of the design solution, and development of the course configuration) during two half-day workshops with key informants. The fourth step (testing of the course components) was addressed in Phase 3 of this study.

For *conception of the design solution,* key informants included a group of five wheelchair users and three caregivers. Each wheelchair user was at least 18 years of age, had used a wheelchair for at least two years, and had experience going out into the community with their wheelchair during winter months. Key informants were first presented with a sketched draft of possible design solutions previously developed by the research team through collaborative discussions, existing literature, and Phase 1 results. The draft design was configured for an existing sheltered outdoor space at the proposed site (a rehabilitation hospital). The draft course sketches consisted of modular sidewalk ramps (some of which were horizontal, sloped, or canted sideways) which could be integrated to create winter mobility obstacles. Each ramp consisted of a different winter condition through which wheelchair users would navigate (i.e., ice, water, deep snow, ruts, and slush).

The research team explained the project intent, and participants were invited to write, draw, or design changes on print versions of the draft design. Next, participants verbally described their ideas, with the co-design lead illustrating these in real-time. This was particularly important because once all participants understood the drawings, a common language was established, allowing everyone to contribute. The research team contributed input to concretize, give form, and translate the ideas into various design proposals. All proposed ideas were discussed collectively until a consensus proposal was achieved. By the end of the session, participants had comprehensively identified winter barriers faced by wheelchair users (see Table 1 for a list and description of barriers) and discussed how the initial draft design might be further enhanced (See Table 2 for a list of discussion topics and descriptions.).

The consensus proposal was consolidated by the co-design lead into a more refined graphic depiction (See Figure 1 for a detailed illustration of the results). The course included five sections: (1) platforms with side slopes similar to what wheelchair users encounter propelling on the sidewalk) and covered with a variety of conditions, including hard-packed snow, ice and slush; (2) a miniature ice rink where users can practice mobilizing on icy surfaces; (3) curbs and curb cuts that each feature a different winter condition as well as windrows piled at the bottom of the

TABLE 1 Identified barriers from wheelchair users' and caregivers' perspectives.

Identified barriers	Description
Ice ruts	An ice rut is a groove worn into a path from foot traffic, cars and bicycles. These ruts result in slippery and uneven surfaces, which cause difficulties when mobilizing a wheelchair.
Deep snow	Thick layers of snow require wheelchair users to exert significantly more effort when mobilizing and are often impassible
Slippery ramps	Ramps covered in ice or slush result in decreased traction while mobilizing. This creates a barrier as wheelchair users slide down ramps and require more effort or assistance to clear the obstacles.
Big chucks of snow	Chunks of hard-packed snow can make their way onto sidewalks after snow removal. These chunks impede mobilization as users attempt to clear the obstacle.
Uncleared sidewalks	After heavy snowfalls, users identified that sidewalks were not cleared. This results in users resorting to mobilizing on the roads, which makes them vulnerable to motor vehicle accidents.
Windrows	Snowplows and foot/vehicle traffic cause an accumulation of snow to pile at the end of sidewalks and curbs. This creates an obstacle that wheelchair users must pass to cross a street.
Snowy ruts and uneven paths	Tire tracks from snowplows on the sidewalk result in slippery and uneven surfaces.
Temperature-related technical problems	Cold weather may cause components of an individual's wheelchair to freeze or malfunction (e.g., wheelchair levers and clasps becoming frozen due to frigid temperatures).
Extreme temperatures	Participants identified that cold weather resulted in chances in spasticity, which caused difficulties when mobilizing.
Physical demands on caregivers	Caregivers discussed the physical demands experienced as they helped wheelchair users in the winter. Physical demands include pushing users through deep snow or ruts.
Lack of education re: winter mobility issues	Participants stated that they perceived that the general public lacked education in the difficulties wheelchair users face and how they could provide assistance.

TABLE 2 Topics that emerged in the first co-design session.

Topic	Description
Ensuring ecological validity	SNOWMAN course components should accurately represent barriers faced by wheelchair users in the winter. These included: a variety of winter surfaces (e.g., ice, slush, hard-packed snow, and deep snow); sidewalks and ramps of variable grades and angles to emulate uneven surface conditions; sidewalks with windrows (i.e., simulating those created by snowplows, car tires and footsteps); and adding curb cuts at the ends of ramps with ruts, divots and accumulations of snow, to mimic unmaintained and/or uncleared sidewalks.
Balancing safety and variability	The course should balance safety with the inclusion of realistic yet difficult obstacles. The range of obstacles should enable people to progressively build their skills comfortably and access varying levels of challenge for skill development.
Making it fun	While the main purpose of the SNOWMAN course is training and device development, participants suggested adding areas where users could enjoy winter leisure activities, such as a miniature ice rink for adapted hockey or curling.

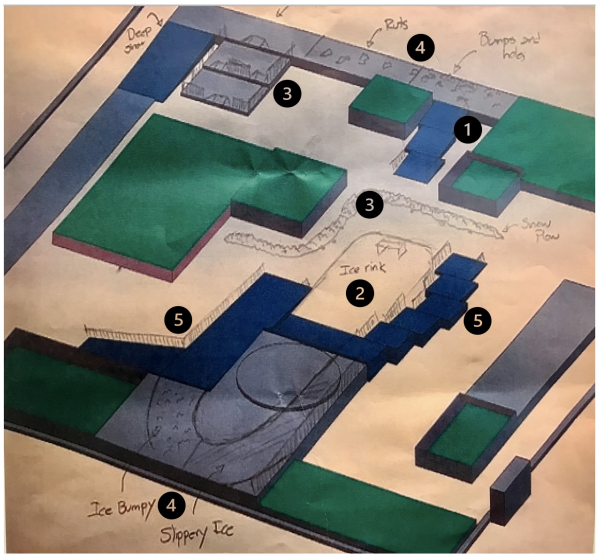

FIGURE 1
Initial consensus design proposal. Numbers align with section descriptions provided in manuscript text.

entrance to mimic unmaintained/uncleared sidewalks; (4) a path of uneven winter surfaces that wheelchair users typically encounter in the community such as ice ruts, deep snow, and large chunks of snow, and (5) modular ramps at various slopes with different winter conditions.

For *validation of the design solution and development of course configuration,* a second co-design workshop was conducted with six additional key informants (i.e., service providers, policymakers, and professionals with expertise in landscape architecture and engineering). The refined consensus design from session one was presented for criticism, enrichment, and confirmation, with the goal of enhancing the design and setting parameters that would result in a realistic, practical, and feasible solution (See Table 3 for details of discussion topics). They expressed enthusiasm for the concept and identified additional uses for such a course but also proposed some feasibility concerns regarding setup, maintenance, and safety. For instance, they advocated reducing the proposed grade of slopes to be within accessibility guidelines rather than the steep "ski slope" that had been proposed by the first group. They identified the need to add rails to higher platforms to prevent accidental falls and the need to create barriers to areas that might be hazardous if individuals were able to use the course without support or supervision. Based on the proposed conceptual design in session one and subsequent support and refinement provided in session two, we felt confident in our stakeholders' validation of the SNOWMAN course. The validated results from the second co-design session were defined using Solidworks 3D design software (Dassault Systems, Waltham, MA), producing specifications for the construction of the course components (not shown).

TABLE 3 Topics that emerged during the second co-design session.

Topic	Description
Exposure and education	Clinicians endorsed the importance of introducing clients to winter conditions and challenges, for instance: exposing clients to cold weather to assess its impact on spasticity; navigating ramps that are manageable in summer but challenging in winter; encountering sand and salt used for preventing slips on roads and sidewalks and how it effects wheelchair components; and dealing with snow glare. The winter obstacle course would allow exposure to winter-related barriers encountered by wheelchair users, fostering educational opportunities and skill development in a semi-controlled setting.
Expanding beyond wheelchair use	Participants saw additional benefits of the winter obstacle course in providing opportunities for clients with gait aids to practice mobilizing in the winter, providing caregivers with training/education, trialling new equipment, and training/educating city employees.
Feasibility	Participants generated important questions to ensure that the winter obstacle course would be realistic, such as: • Who will maintain the course? • How will wheelchair users dry their equipment following trials? • What safety precautions will be in place when using the area? • What are the rules for using the area? • What types of equipment and training do clinicians require before taking clients into the area?

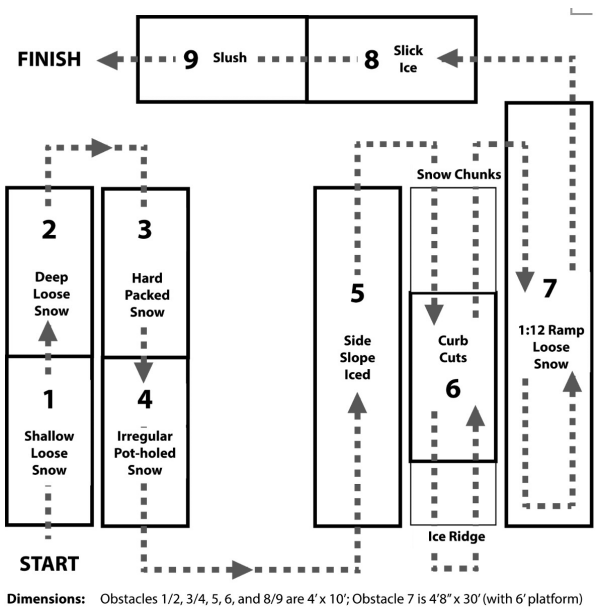

FIGURE 2
Schematic of the SNOWMAN course.

3.3 Phase 3: fabrication of the SNOWMAN course

Due to cost, space, and resource constraints, a reduced-scope prototype of the SNOWMAN course was fabricated in winter 2022–2023. We constructed the standardized course in a large uninsulated covered shed which was unheated and fully exposed on one wall. The course was created in Winnipeg, Manitoba, Canada, where the average winter temperature between November–March is −10.7°C and the average snowfall is 20.9 mm. The course included a defined pathway, taking wheelchair users through a series of nine challenging winter conditions: (1) shallow (2") loose snow, (2) deep (4") loose snow, (3) hard-packed snow, (4) irregular pot-holed snow, (5) iced 5° side slope/sidewalk, (6) two curb cuts with snow chunks and an ice ridge at the two approaches, (7) a 1 : 12 (5°) snow-covered ramp (1/2" snow) with snow accumulation at the base, (8) a slick icy flat surface, and (9) a slushy surface. See Figure 2 for a schematic of the course and Figure 3 for a series of photos of the course in January 2023.

3.4 Phase 4: development of a protocol for standardization of course setup and measurement of component attributes and ambient weather conditions

As there was no literature available regarding the creation of winter conditions, our research team undertook a process of fabricating snow and ice compositions required for each course component. This process was necessarily iterative to achieve conditions that would mimic real-world winter obstacles. Once these were satisfactory, we created a protocol manual to ensure consistent replication. Because the course is situated outdoors, we were unable to control for ambient temperature and humidity; however, most conditions of the course were under investigator control and made as consistent as possible for future testing, training, or evaluation sessions. For instance, water was sprinkled on the icy surfaces with a watering can prior to testing to ensure a comparable coefficient of friction. Loose snow was added to the shallow and deep snow obstacles to ensure correct depth when this had been reduced due to sublimation and were subsequently groomed using a bow rake. Slushy snow was prepared by mixing windshield washer fluid (containing anti-freeze) and soft snow in specific proportions to ensure homogenous and consistent hardness and density. New snow was added to the ramp and groomed for each trial as snow left in place tended to get hard and freeze to the ramp. Additionally, the snow chucks were replaced at the bottom of the curb cuts whenever these were disturbed during use.

Given the specified obstacle composition and the course location outdoors, we also developed a standardized protocol for testing the controllable obstacle snow conditions as well as the uncontrollable weather conditions so these could be documented in a consistent way. Using valid and reliable methods identified in the literature (19), we developed a standardized protocol (available upon request from the first author) for measuring the constructed obstacle snow conditions as well as the ambient weather conditions. This protocol was completed by a research assistant (RA), who was hired to set up, maintain, and groom the course components and to document conditions in preparation for subsequent data collection. The standardized

FIGURE 3
Photo of SNOWMAN course in January 2023.

protocol involved measuring and recording ambient temperature and humidity; snow depth, surface temperature, hardness, and density on snow-covered obstacles; and coefficient of friction on icy surfaces.

4 Discussion

Based on expert stakeholders' lived experiences with winter conditions, we successfully created a standardized outdoor wheelchair mobility course consisting of nine unique winter obstacles and a course construction and maintenance protocol. Following the co-design sessions, it was clear that wheelchair users, caregivers, clinicians, professionals, and policymakers were supportive of project SNOWMAN.

Through the project, we identified the need to develop a space that incorporated multiple and varied winter conditions routinely encountered to enable comprehensive comparison and evaluation that could differentiate between different mobility devices and solutions. Furthermore, we identified the need to create a context that was of sufficient space to replicate real-life challenges (i.e., enough of the obstacle to capture authentic encounters and to replicate the authenticity of overground propulsion). Although standardization of conditions in such an outdoor course may not mirror precisely reproducible indoor laboratory environments, a strength of this winter test course is its applicability to varying,

real-world conditions that are not captured in an ecologically valid way by traditional research settings.

The development of the SNOWMAN course provides an opportunity to address the evaluation of wheelchair mobility skills in diverse contexts. Existing outcome measures, such as the Wheelchair Skills Test (19, 20) are comprehensive in scope of mobility skills included but may not address the same breadth of environments and surfaces, particularly in standardized testing. SNOWMAN may provide the opportunity to use such outcome measures in a complementary way or potential adaptation of existing measures for evaluation in winter environments.

The project aims to offer several additional potential benefits, supported by the various stakeholders across the study phases, that extend beyond creation of a controlled and safe environment for wheelchair users to develop their winter mobility skills. Practicing wheelchair skills in this area may assist wheelchair users in gaining confidence which may ultimately translate to increased participation in the community. SNOWMAN can serve as a testing ground for mobility device manufacturers to innovate and improve winter-ready devices. Clinicians can use this space to prepare clients for winter challenges, offering practical techniques and education. Additionally, it allows clinicians to observe clients using new mobility equipment and gather evidence to support equipment funding. Lastly, it could provide a training platform for civic employees responsible for snow clearing and accessible transportation, potentially improving overall winter accessibility in the community.

5 Conclusion

The development of SNOWMAN represents a step toward addressing a critical research gap in providing areas for wheelchair users to develop skills and overcome challenges faced during winter. Through this process, we have created a unique environment that provides a context for winter-specific mobility device innovation and testing. This project has been a collaborative effort involving researchers, wheelchair users, caregivers, clinicians, professionals, and policymakers, all of whom have demonstrated strong support for this initiative. The next step in this research is to use the SNOWMAN course to evaluate whether it is an ecologically valid course that can distinguish between various wheelchair configurations and user abilities. Overall, SNOWMAN is a groundbreaking initiative with the potential to positively impact the lives of wheelchair users and the broader community by enhancing winter mobility and accessibility.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by University of Manitoba, Bannatyne Campus Research Ethics Board. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any identifiable images or data included in this article.

Author contributions

JR: Conceptualization, Investigation, Methodology, Project administration, Writing – original draft. EG: Conceptualization, Formal Analysis, Investigation, Methodology, Project administration, Writing – review & editing. JB: Conceptualization, Investigation, Methodology, Writing – review & editing. EM: Conceptualization, Investigation, Methodology, Writing – review & editing. K-LH: Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Co-design knowledge mobilization tools for universal accessibility in municipalities

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Introduction: Modern research teams are re-evaluating conventional methods with the aim of improving the usefulness of knowledge for users, focusing on the role of knowledge users in shaping innovation. In disability field, encouraging participatory research inherently involves diverse perspectives and inclusion, which aligns with the principles of universal accessibility. By actively involving individuals with various backgrounds, abilities, and needs in the research process, we can better understand and address the challenges faced in adopting universal accessibility. This approach ensures that solutions are more comprehensive, inclusive, and effectively cater to the needs of all individuals, fostering a more equitable and accessible environment for everyone. Despite municipal organizations mandating universal accessibility action plans, they lack tools for efficient implementation. The aim of this study was to develop knowledge mobilization tools tailored to a specific municipal context in Quebec, Canada, to facilitate the implementation of universal accessibility measures by municipal employees.
Methods: The co-design process employed in this study was organized into four distinct stages, following the Morales model: (1) Exploration (2) Co-Design (3) Validation (4) Development.
Results: Stages one and two highlighted the employees' lack of awareness about universal accessibility issues and their need to have more information and resources about how universal accessibility is encountered in their work. A steering committee co-designed three video vignettes about universal accessibility, the city's action plan and measures included in it.
Discussion: The co-design approach used in this study allowed us to observe the non-linear nature of partnership research with an organization as complex as a municipality. Our study shows significant advantages of collaboration between the municipal sector and research.

KEYWORDS

co-design, implementation, universal accessibility, municipal organization, disability

1 Introduction

In response to the scarcity and delays in implementing research results, research teams are reassessing their methodologies to improve the accessibility and usability of knowledge for end-users. One approach to accelerate the adoption of knowledge is the use of participatory research paradigms that highlight the significance of actively engaging knowledge users in knowledge generation process and implementation of innovative solutions (1–4). Many studies have shown that involving knowledge users in the knowledge creation process significantly and positively impacts the implementation of

innovation (5, 6). It also positively influences individual changes in knowledge, attitudes, and beliefs (7–9). The benefits of engaging stakeholders in the implementation process have been supported in the knowledge production process (4, 7, 10). For example, it enables stakeholders to contribute to the design and implementation of accessibility measures. This collaboration ensures that solutions meet the specific needs of users (7). It also promotes acceptance and compliance with accessibility measures. Collaborating with local community organizations increases awareness and acceptance of accessibility initiatives, leading to higher compliance rates and sustainable results.

There is a significant importance in advocating for the utilization of participatory research and involving stakeholders such as decision-makers, municipal actors, disabled people, or others working in the disability field to address, among other things, universal accessibility of social and physical environments issues. Participatory research is seen by researchers and partners as a relevant method for accelerating and promoting the adoption of universal accessibility measures, thereby ensuring equitable social participation and rights for Persons with Disabilities (PWDs) or marginalized populations and fostering their independent engagement in various face ts of society. Universal accessibility refers to the character of a product, process, service, environment, or information that, within an equity vision and through an inclusive approach, enables any individual to engage in activities independently and achieve equivalent outcomes (11). In this project, we focused on the accessibility of the physical and social environment.

Municipal organizations play a leading role in developing universal accessibility solutions in urban contexts. With the adoption of the Convention on the Rights of Persons with Disabilities (CRPD), municipalities have been at the forefront of implementing best practices in universal accessibility (12, 13). In the province of Quebec, Canada, municipalities of more than 15,000 citizens must develop universal accessibility action plans (12, 14), which are policies detailing specific measures for planning project organization activities (15). Despite their mandate to draw up a universal accessibility action plan, municipal organizations currently face a lack of knowledge mobilization tools and strategies to facilitate the implementation of the diverse measures outlined in these plans by the decision-makers, managers and employees (16).

This can be attributed to contextual factors (e.g., recent emphasis on universal accessibility issues, large number of universal accessibility measures and administrative rules) (17) and complexities lying within municipal organizations (e.g., multiple hierarchy levels, staff retention, large number of employees and administrative units, diversity of actors and stakeholders) (9, 17–19). By 2050, it is estimated that more than two-thirds of the world's population will live in urban areas (20). With an increasing number of urban dwellers and a substantial growth of global population of individuals with disabilities (21), active involvement of municipal employees in the implementation of universal accessibility measures holds significant benefits and empowers them to contribute to a more inclusive and equitable society (22, 23). Haynes et al. (24) demonstrated that in the implementation of partnerships to strengthen policy, knowledge mobilization activities used to foster engagement, capacity building and partnership formation yielded positive results, and that co-design could be strengthened by greater sharing of the decision-making process.

In response to this challenge, a city in the province of Quebec (Canada) has recognized the need to engage in a co-design process to develop knowledge mobilization tools and strategies that will optimize the implementation of universal accessibility practices. Co-design aims for active participation and integration of users' points of view throughout the design process (25). As such, co-design seemed entirely appropriate for this partnership research, where the involvement of researchers and municipal stakeholders is equally important at each step of the project. Besides, the co-design approach in organizations helps the stakeholders to realize their project goals (26). It provides individuals with more direct involvement in defining their needs and priorities and collaboratively finding solutions, influencing decisions, and achieving better outcomes (27).

This study took place in a large tourist city in the province of Quebec, with a population of around 550,000 citizens and a metropolitan community of about 840,000 people. This municipal organization has 5,000 full-time employees working as managers, civil servants, professionals, technicians, workers, or seasonal workers in 33 administrative units. The City has involved 25 of the city's administrative units to varying degrees in the universal accessibility action plan. In each of the administrative units involved in the action plan, an employee is designated as responsible for universal accessibility. The City's internal Universal Accessibility Committee brings together the 25 employees responsible for each unit. These employees are members of each team who have volunteered for this role and who have developed expertise in universal accessibility through their training or experience. This municipal organization was selected for this study based in its needs to develop tools, and because of the lack of scientific and practical knowledge about the organization's internal context, which may or may not allow the implementation of universal accessibility measures. It's also a large city with significant needs in terms of universal accessibility. Indeed, it has a complex hierarchical organization and significant needs due to its aging population and the heritage character of its environment (28, 29).

In that context, the main objective of this study was to develop knowledge mobilization tools tailored to a specific municipal context to facilitate the implementation of universal accessibility measures by municipal employees. The secondary objective was to address the relevance of a co-design method in a municipal organizational context.

2 Methods

Co-design is a participatory methodological process that facilitates the solution development through collaboration between various stakeholders, such as researchers and partners. Co-design has an individual, social and material dimension that

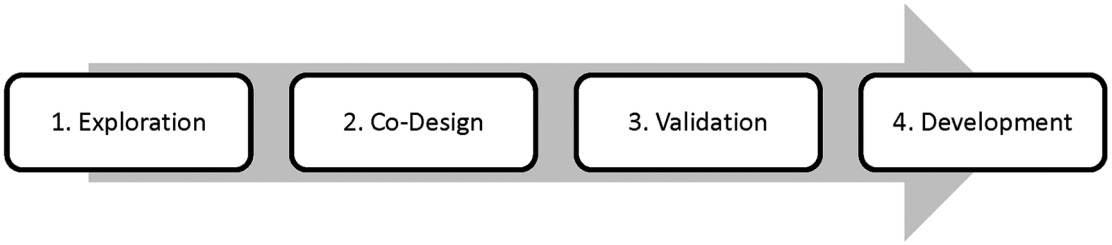

FIGURE 1
Morales' model of co-design process.

encourages the creative process and facilitates multi-professional negotiation by transcending restrictions (30). The research process employed in this study was organized into four distinct stages, following the model proposed by Morales et al. (31): (1) Exploration (2) Co-Design (3) Validation (4) Development (see Figure 1). The exploration phrase aims the better understand the problem and the participant's experience. The co-design phase is to promote creative thinking among the team to design a solution. The validation phase is to evaluate pertinence and feasibility of the ideas and development aims to translate the results into a tool or object (31). The co-design process was carried out with stakeholders from the municipal organization who are acknowledged by their peers for their expertise and interest in universal accessibility.

2.1 Exploration

The exploration step employed an experience-centered approach i.e., to explore users' experience to better grasp the problems to be solved (25). It enabled the gathering of participants' experiences and perceptions regarding the context. This information was significant because the subsequent stages of the process were built upon the data obtained in this phase. The co-design phase was subsequently grounded in a genuine need expressed by the individuals directly affected by the proposed solution. During exploration stage, our data collection was conducted through the combination of survey and focus groups.

2.1.1 Survey

A survey adapted from the Consolidated Framework for implementation research (CFIR) (32) allowed to collect information and insights regarding the barriers and facilitators of implementing universal accessibility measures. To create this survey, we conducted a rapid literature review (33) of the utilization of the CFIR determinants (34) in assessing implementation in organizational settings. CFIR is a framework widely used in implementation, which combines 19 theories of implementation from various disciplines. It is made up of 39 constructs groups under 5 domains: intervention characteristics, outer setting, inner setting, characteristics of individuals and process (34, 35). This framework offers a common language about facilitators and barriers of implementation and supports implementation of evidence-based practices from design to evaluation (19). It recently has been used for policies interventions and fits well to evaluate complex interventions such as urban social policies (19). This process facilitated the identification of survey questions tailored to the specific municipal context, as recommended by Nilsen and Bernhardsson (36). Three authors (MC, MEL, FR) and two other experts in knowledge mobilization and universal accessibility carried out this process. A preliminary version of the survey was presented to the municipal partners. Three iterations were required to ensure that the questions were customized for the local context and easily understandable for municipal employees. The changes made were clarifications of questions to ensure that the language would be clear and well understood by all employee respondents.

The questionnaire consisted of 30 Likert-type questions and 5 briefs open-ended questions. The number of questions that needed to be answered depended on the response to the initial question in the survey, which inquired about the respondents' familiarity with the municipal organization action plan. This first question was important because of the low level of knowledge of the action plan reported by this city's municipal employees according to our previous study (16). If respondents were familiar with the action plan, they had to answer an additional 10 questions, bringing the total to 40 questions. The questionnaire was distributed to all municipal employees via mass email. Two follow-up emails were sent. The results of the questionnaire were analyzed using frequency distribution, for the Likert-type questions (37) and content analysis to extract meaningful insights and themes for the qualitative questions (38, 39).

2.1.2 Focus groups

Three focus group sessions of 120 min each were conducted. The aim of these focus group sessions was to have a better grasp of all participants' experiences and perceptions regarding universal accessibility in a municipal context, along with complement the information gathered from the questionnaires. These focus groups involved employees of seven administrative units, selected based on their responses to the questionnaire and their active engagement in universal accessibility initiatives within the city. A discussion guide was prepared, drawing from the questionnaire results, to delve deeper into the survey findings. The questions aimed at gathering more information on the actions

taken in universal accessibility, the information and tools they needed to facilitate the implementation of universal accessibility measures, and the content and format of these tools. Additional questions were incorporated to comprehensively document the diverse needs identified. The discussions were recorded for transcription. An inductive thematic analysis (38–40) was done by the first author. The coded results were then discussed within the research team and with partners. At this stage, validation of the analysis with methodological experts from the research team (MEL, FR) and with the partner improved the rigor of the analysis process.

2.2 Co-design

The second phase of our co-design process aimed to stimulate creative thinking among partners and research team members (31). To initiate this co-design phase, a steering committee was established, consisting of five employees dedicated to promoting universal accessibility within their respective administrative units. A preparatory meeting was convened to provide context of the project and to present the findings from the survey and focus groups. Over the course of six months, the committee had six meetings of two hours. These meetings were held virtually through the Teams platform and were recorded. The committee engaged in discussions regarding the format, content, and modalities of the knowledge mobilization tools. Following each meeting, the research team made improvements to the tools suggested, which were then presented with modifications and discussed in the subsequent meeting. These iterative cycles enabled the adaptation of prototypes tools tailored to the specific context and needs of the city.

2.3 Validation

The third step involved presenting the prototypes that emerged from the co-design sessions with the steering committee to a broader audience of municipal employees, which was all members of the City's universal accessibility committee. The goal was to confirm whether the tools effectively addressed the needs and barriers commonly experienced by their colleagues, the translation process into formal tools, along with the feasibility of their potential implementation. To achieve this, the stage 2 outcomes of the Morales model were shared with the City's internal committee on universal accessibility, composed of twenty-five employees responsible for universal accessibility within their administrative units. Notes were taken during the meeting. The discussions held in this step served to validate the appropriateness and relevance of the co-designed tools and provided all the necessary input to proceed with the final development of these tools and their subsequent implementation.

2.4 Development

The final step involved translating the prototypes into formal tools that would be used within the administrative units. Considering the municipal organizational context, the implementation strategy of the knowledge mobilization tools, including the prototypes developed by the steering committee and the research team, was initially presented to the directors of the administrative units. This step allowed the managers to gain clarity regarding the expectations for their employees and to better understand the relevance of these tools. The implementation process started within three pilot units, namely Heritage and Culture, Communication, and Citizen Engagement. These teams were selected as they corresponded to the respective teams of three members of the steering committee. This enabled faster pre-testing and better feedback. To ease the implementation of the tools, an instructional guide was developed and presented to the three responsible for universal accessibility of the pilot units. This animation guide, available in a printed or not word format, was used to facilitates the presentation of the tools during team meetings and supported discussions around universal accessibility among their colleagues.

3 Results

3.1 Exploration

3.1.1 Survey

3.1.1.1 Participants

Employees from all administrative units completed the survey ($n = 277$; response rate = 32%). They had different types of job: officials (56%), professionals (30%), equipment manager (7%), other (7%). Nearly half of the employees had been working in their current position for more than 5 years (47%).

3.1.1.2 Implementation barriers

Regarding universal accessibility measures, the results showed that employees find universal accessibility principles complex (69%) and hard to implement (76%). They also have difficulty seeing the adaptability of the measures to their reality as municipal employees (60%). Concerning outer setting, more than half (53%) of employees said they needed to better understand who universal accessibility measures were for and who they would serve in the community. Regarding inner setting, employees said they lack the resources and tools to implement universal accessibility measures (59%). In terms of individual characteristics, knowledge and beliefs were identified as a barrier. Employees said they knew what universal accessibility was (64%), but they barely knew that the city had a universal accessibility action plan (67%) and did not receive a presentation of this action plan (77%). Also, they didn't know what role universal accessibility played in their work or administrative unit (40%). As for the process, the results of the survey highlighted that employees were unaware if their manager has planned to implement universal accessibility measures within the unit (63%). They also didn't know what was planned to execute (71%) and evaluate (94%) universal accessibility measures in their team.

3.1.1.3 Tools needed

The results of the inductive thematic analysis brought out specific needs for tools. Visual information tools such as videos, documents or infographics about universal accessibility, the action plan and specific measures for each unit was the most mentioned need (40%). Other needs mentioned included a short and specific guide about universal accessibility actions in their daily work (15%), toolbox with references (13%), checklist (10%) and sensitivity trainings (9%). Some employees also mentioned more specific needs such as identification of the responsible for universal accessibility in their unit (3%), adapted equipment for citizens (2%), or dedicated budget for universal accessibility measures (0.7%). Only 2% of the people mentioned having all the tools they needed. For example, the recreation, culture and events teams reported a greater need for specialized equipment, or a budget allocated to accessibility, given their proximity to citizens. On the other hand, employees in teams further away from citizens (e.g., Finance, Human Resources) were more interested in identifying the person responsible for universal accessibility in their team, so that they could refer to the right person.

3.1.2 Focus groups

The three focus groups were held with respectively 6, 4 and 4 participants ($n = 14$) from 7 administrative units (Event management, Office of Major Events, Citizen Engagement, Human Resources, Communications, Records and Archives, and Culture Heritage).

3.1.2.1 Facilitators

Regarding universal accessibility measures, employees had a good perception of the implementation of universal accessibility measures. They mentioned the benefits of universal accessibility measures for them and their colleagues as being themselves citizens. Other facilitators to implementation were underlined toward inner setting. Developed networks and communication with other organizations and with citizens, a positive learning climate within the municipal organization, relative priority to improve implementation of universal accessibility measures shared by participants and leadership engagement of their team's manager were reported as helping them to prioritize this issue. For the characteristics of individuals, all participants reported self-efficacy and positive attitudes towards universal accessibility measures. Finally, representatives of administrative units in universal accessibility [champions] and consultations or partnerships with PWDs during activities was highlighted as process facilitator in the implementation of universal accessibility measures.

3.1.2.2 Barriers

Barriers were highlighted by participants of all groups. First, when considering intervention attributes, employees are raising concerns about the absence of adaptability to their tasks or unit, limited trialability within certain teams, and the complexity of universal accessibility measures. Second, the lack of knowledge about external policies and incentives or about what are the people with disabilities' needs is reported as an outer setting barrier by employees. Readiness for implementation has been tackled as an inner setting barrier, due to the lack of available resources. The implementation climate was also discussed as barrier because of the impact of pandemic (use of virtual mode) and work overload due to staff shortage (learning climate), the relative priority and the access to knowledge and information. Regarding characteristics of individuals, knowledge and beliefs were underlined by 3 participants as a barrier because of false beliefs or stereotypes about universal accessibility. Participants also mentioned they perceive that their organization talks about accessibility without being accessible for their own employees. Process was not discussed as a barrier in the focus group.

3.1.2.3 Needs

When asked to discuss the different tools that employees might need, employees stated aspects related to the content and format of these tools. Participants named testimonials of PWDs as having a significant impact on their awareness. Guides and resources on universal accessibility about how to plan an accessible event or activity, or how to answer special needs of a city employee were also mentioned. For format, sensitive training, short video clips, intranet toolbox and informal discussions around coffee break with colleagues were discussed. There was no consensus on the preference between virtual or face-to-face activities.

Table 1 shows results of survey and focus group classified according to the CFIR domains as facilitators or barriers to the implementation of universal accessibility measures by municipal employees. This synthesis of facilitators and barriers served as a starting point for the subsequent codesign phase.

3.2 Co-design

The co-design sessions followed the exploration phase. A total of seven meetings were necessary to complete the co-design process. During the initial session, the research team and the steering committee collaborated to categorize and prioritize the various tools and barriers identified during the exploration phase. Given the project deadlines, the committee opted to initiate the co-design process by creating three video vignettes. The development of videos seemed to be appropriate to the research context since they can convey a general idea such as universal accessibility more easily and clearly than other media. They also facilitate retention of the knowledge we aimed to convey since they respond to the three main principles of knowledge translation according to Bennet and Jessani (41), i.e., the presentation of solid, accessible and contextualized knowledge, through relational dialogue and exchange, and based on a skills base of researchers and knowledge users creating opportunities for knowledge translation. The purpose of these videos was to raise awareness among municipal employees on universal accessibility, in addition to addressing the major barriers identified (lack of information, knowledge, need for a deeper understanding of how universal accessibility affects employees in their work).

TABLE 1 Facilitators and barriers to implementation of universal accessibility measures by municipal employees according to the CFIR.

CFIR domains	Facilitators		Barriers	
	Item	CFIR construct associated	Item	CFIR construct associated
Intervention characteristics	Benefits for them or colleagues	Relative advantage	Absence of adaptability to their tasks or unit	Adaptability
	Positive perception of universal accessibility measures	Need of evidence strength and quality	Complexity of universal accessibility measures	Complexity
Outer setting	Developed networks and communication with other organizations and with citizens	Cosmopolitanism	Lack of available resources or information	Individuals needs and resources
	Representatives of administrative units in universal accessibility [champions]	Peer pressure		
	Action plan	External policies and incentives		
Inner setting	Developed networks and communication with other organizations and with citizens	Network and communications	Readiness of change by the work teams	Readiness for implementation
Characteristics of individuals	Self-efficacy	Self-efficacy	False beliefs or stereotypes about universal accessibility; lack of knowledge on universal accessibility or on action plan	Knowledge and beliefs about intervention
	Positive personal attitudes with universal accessibility and their responsibility	Individual identification with organization		
Process	Leadership engagement of their team's manager	Engaging	Unaware if their manager has planned to implement universal accessibility measures	Planning
			Do not know what was planned to execute	Executing
			Do not know what is evaluated	Reflecting and evaluating

The subsequent six meetings of the steering committee followed an iterative process between the research team and the steering committee regarding the content of the videos. Two sessions were dedicated to each video vignette. During the first session, an initial scenario was proposed by the research team, with the integration of scientific content. This proposal was subjected to feedback and critique from the steering committee members. Their suggestions for modifications were considered to tailor the content to their specific municipal context. Subsequently, the research team revised the scenario, incorporating the received feedback, and presented a second version during the second session. This second version was then reviewed and validated by the steering committee. This iterative process was repeated three times, corresponding to the creation of the three video vignettes. These six sessions were spaced out over six months, with one meeting occurring each month.

3.3 Validation

The modified version of the content of the video vignettes, based on the results of the co-design phase, was presented at a meeting of the City's internal universal accessibility committee. This committee validated that the content of the videos was meeting the identified needs and was suitably customized to the context. They also gave further explanations to ensure a comprehensive understanding of the mandates for all universal accessibility units so the development and implementation would be adapted to realities. They were able to understand their role in the further implementation of the video within their respective units.

3.4 Development

A professional videographer was engaged to shoot the videos, for a high-quality production. For the first video clip, the cast included both a city employee and a person with an intellectual disability (PWD). The PWD received financial compensation for their participation in the first video capsule, and all actors involved in the project signed consent forms. In the second video clip, two city employees took on the acting roles, and for the final video, a total of 8 employees participated in the filming process. The videos had durations ranging from 3 to 5 min each. Here's a brief overview of the content and style of each video:

- **First Video:** This video introduces the concept of universal accessibility and illustrates how it is applied to city services.
- **Second Video:** The second video presents the city's action plan and outlines the various measures planned by the municipality to promote universal accessibility.
- **Third Video:** In the third video, employees share personal accounts of how universal accessibility is integrated into their work and discuss their accomplishments in this domain. This video takes on a more direct and storytelling style, with participants speaking directly to the camera.

Each video production required half a day to a full day of shooting to ensure the content was well-crafted. To disseminate the different video capsules within the administrative units, an implementation strategy is currently developed collaboratively by the research team and the steering committee. This strategy will undergo validation by the relevant departments within the organization. Following this, an evaluation strategy will be implemented in three test units (Heritage and Culture, Communication, and Citizen Engagement) to fine-tune the implementation approach for subsequent administrative units.

This all-encompassing approach will enable us to integrate the videos as effectively as possible in the workplace, and to achieve the desired objectives.

4 Discussion

This study reported a participatory process that aimed to create knowledge mobilization tools for municipal employees to facilitate the implementation of universal accessibility measures outlined in their action plan. In this research, we used Morales and colleagues' co-design methodology within a collaborative partnership in a municipal organization context. Utilizing a co-design approach in collaboration with a complex entity like a municipality underscores the need for tailored knowledge mobilization strategies to engage various stakeholders throughout the implementation process.

Our study illustrated that the process employed allowed us to create tools and develop an adaptable implementation strategy aligned with specific needs and context. Our results differ from those reported by Dubois et al. (42) who argument that co-design requires collective action and effective organization of the environment and is not optimal in a complex context. Our research illustrated that it is possible to employ a participatory-based co-design approach in intricate organizational settings such as municipalities. However, we still don't know what exact characteristics of the context facilitates or hinders the co-creation process. Even though we know some of context characteristics of this City, they have not been measured. We can make assumptions about it with the use of the CFIR framework, but they are not empirically supported. We can therefore assume that we are still lacking tools that are well known and well shared, so that they can be put to good use. It would be interesting the measure the different characteristics, so we can draw more solid conclusions. Although the municipal organization is complex and highly hierarchical, there seems to be a coherence in opinions and needs shared by employees. It is possible that, in different contexts, organizational changes during a co-design process could rather diminish the efficiency of the process, prevent such validation of results and limit generalizability. For example, authors demonstrated that co-design in a healthcare organizational context presented significant challenges due to organizational resistance to change, and the need for change in culture, behaviors, time, resources, and managerial support within the organization (43). We believe that the weight of municipal policies regarding universal accessibility also helped counter this resistance to change and released resources to facilitate the process. In fact, although few employees were aware of their administration's universal accessibility action plan, the existing policy on this subject enabled us to use it as a lever for change to demonstrate the importance of this issue. It allows for a certain momentum, fostering the commitment of municipal stakeholders in the process. This also justifies our relevance in developing tools that promote understanding of this action plan and the implementation of the measures outlined therein.

Following the linear four-stage process based on the Morales (31) model, we observed that within a municipal organization, the process naturally became more iterative due to the multiple validations required at every stage. In the context of partnership research, these iterations at different stages showed greater significance as they impact positively partner engagement and involvement levels throughout the project, ultimately influencing the implementation process. These iterations also enabled a more natural diffusion of the process within the organizational structure, following the organization's habitual ways of communicating. The iterative nature of the co-design process appears to be recurring in studies on design. Indeed, Steen (44) emphasize that it is normal, and even beneficial, for the co-design process to be iterative, ensuring alignment between needs and responses. Other studies in the field of disability, which have conducted co-design studies or processes, have also highlighted the relevance of these iterations to ensure a comprehensive understanding among all stakeholders and to address the needs of the population involved (45, 46).

Emmons and Chambers (47) emphasized the importance of applying implementation science strategies to social and urban policies to enhance our ability to address health-related social determinants. They underscored research's role in understanding why intervention succeed in specific context. Integrating the CFIR framework into data collection and analysis in our study provided deeper insights into the connection between results and the implementation of universal accessibility measures, particularly within municipal context. Labbé et al. (19) also highlighted CFIR's relevance in municipal settings. CFIR's suitability for evaluating complex intervention, like universal accessibility measures, supported our partnership research and co-design process, enabling better identification of implementation facilitators, obstacles and stakeholders needs. Contextual understanding is pivotal in implementation science, as it elucidated what works and why (36). According to Nilsen (48), frameworks in implementation science aim to describe and/or guide the process of translating research into practice, understand and/or explain what influences implementation outcomes or to evaluate implementation. Theoretical frameworks, such as CFIR, ensure methodological robustness and mitigate challenges in partnership research. However, their constrained utilization of these frameworks beyond healthcare contexts (49, 50), hinders effective co-design processes across various settings, including patient involvement in service care (51–53).

4.1 Strenghts and limitations

This participatory research enabled us to learn more about the co-design process with a municipal partner. Our reflections and conclusions highlight some of the strengths and limitations of our study. Despite the large and diverse group of participants during the exploration phase and the various stakeholders involved in the co-design and validation phases, the survey results, focus group discussions, and co-design deliberations all converged on a common finding. Municipal employees expressed a lack of information, knowledge, awareness, and resources concerning universal accessibility

measures. However, it's important to note that this outcome may also be attributed to the co-design process itself. This coherence between the results of the different stages of the research is one of our study's strengths. Indeed, the co-design process made it possible to verify and triangulate the data at the different stages with different methods, and to obtain a saturation of data on the implementation barriers and facilitators of universal accessibility measures by municipal employees. We believe this coherence is mostly attributable to the initial context. Moreover, the flexibility of the process and the various iterations have ensured the development of knowledge mobilization tools adapted to the reality of the context and meeting a real need on the part of knowledge users.

However, we note as a limitation the fact that only one person with a disability was involved in the first video. It would have been interesting to have a person with lived experience on the steering committee, to ensure that the ideas conveyed in the video vignettes reflected the real-life experience of the people concerned. However, we would point out that the primary objective was to reach out to municipal employees, which is why their colleagues were the main participants in the videos.

4.2 Future research

The creation of this partnership research aimed to produce usable and transferable results that consider knowledge and expertise of stakeholders (26). Our study highlights significant advantages of collaboration between the municipal sector and research. It seems to facilitate social relevance of research, the creation of tools and interventions better suited to the context, and a higher potential for user engagement with the results. Consequently, these solutions become sustainable and beneficial to the entire community. Partnered research allows for the implementation of more robust and efficient solutions to complex problems. By establishing a partnership between the municipal sector and health research, it becomes possible to develop and implement effective strategies and initiatives that can have a positive impact on the lives of individuals with disabilities. Also, the participation of a large number of municipal employees from diverse backgrounds during the process increased the external validity of our research (40). At times, however, this hampered consensus-building, as we were unable to produce resources that met all needs. So, to begin with, we focused on the needs put forward by the actors involved in the co-design process, based on the needs expressed in the questionnaire and in the focus groups. Finally, we believe that the process used could be replicated in other studies and similar municipal contexts, but that it could also lead to the creation of other tools, according to need.

5 Conclusion

The co-design approach used in this study allowed us to observe the non-linear nature of partnership research with an organization as complex as a municipality. In fact, several iterations, and exchanges within the team and with municipal administration departments were necessary to ensure that everyone was comfortable with the process and deliverables. We also note that involving knowledge users in the process from the outset, and at every stage of the project, enables the development of solutions tailored to their real needs. Collaboration between the research team and the municipal organization's team ensured an adapted response to real needs of the municipal partner. Involving knowledge users from the outset and at every stage of the project was extremely beneficial. Their participation ensured the relevance of our research objectives, and their ongoing feedback enabled us to adjust our work. We believe this partnership process reinforced acceptance of the research results since they were able to see the evolution of the project and that their involvement fostered greater confidence in the conclusions reached. Also, by co-creating knowledge, we enriched our understanding of the subject and we learned to overcome some of the obstacles of partnership research, such as adapting to each other's culture and respecting each other's pace.

In the future evaluation of the implementation of co-designed tools, we will assess whether this has had an impact on the knowledge and awareness of municipal employees. We believe that by raising awareness with the video vignettes, employees will feel more sensitive and responsible toward universal accessibility issues. Moreover, this paper highlighted how partnership research and a co-design methodology can be applied with complex partners and complex issues such as knowledge mobilization and universal accessibility.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by Comité d'éthique à la recherche sectorielle (CÉR-S) en Réadaptation et intégration sociale du CIUSSS-CN. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

MC: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing. M-EL: Conceptualization, Formal Analysis, Funding acquisition, Methodology, Resources, Supervision, Validation, Writing – review & editing. FR: Conceptualization, Funding acquisition,

Supervision, Validation, Writing – review & editing. EM: Conceptualization, Methodology, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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SONOICE! a Sonar–Voice dynamic user interface for assisting individuals with blindness and visual impairment in pinpointing elements in 2D tactile readers

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Pinpointing elements on large tactile surfaces is challenging for individuals with blindness and visual impairment (BVI) seeking to access two-dimensional (2D) information. This is particularly evident when using 2D tactile readers, devices designed to provide 2D information using static tactile representations with audio explanations. Traditional pinpointing methods, such as sighted assistance and trial-and-error, are limited and inefficient, while alternative pinpointing user interfaces (UI) are still emerging and need advancement. To address these limitations, we develop three distinct navigation UIs using a user-centred design approach: Sonar (proximity-radar sonification), Voice (direct clock-system speech instructions), and Sonoice, a new method that combines elements of both. The navigation UIs were incorporated into the Tactonom Reader device to conduct a trial study with ten BVI participants. Our UIs exhibited superior performance and higher user satisfaction than the conventional trial-and-error approach, showcasing scalability to varied assistive technology and their effectiveness regardless of graphic complexity. The innovative Sonoice approach achieved the highest efficiency in pinpointing elements, but user satisfaction was highest with the Sonar approach. Surprisingly, participant preferences varied and did not always align with their most effective strategy, underscoring the importance of accommodating individual user preferences and contextual factors when choosing between the three UIs. While more extensive training may reveal further differences between these UIs, our results emphasise the significance of offering diverse options to meet user needs. Altogether, the results provide valuable insights for improving the functionality of 2D tactile readers, thereby contributing to the future development of accessible technology.

KEYWORDS

pinpoint navigation, user interface, sonification and speech interfaces, 2D tactile readers, access to graphical information, blind and visually impaired, assistive technology

1 Introduction

Two-dimensional (2D) and graphical data are an integral part of our daily lives, starting from our early education years, where we explore educational graphics, to complex visualisations like neural network architectures. However, individuals with blindness or visual impairment (BVI) face significant challenges in accessing and comprehending this visual information. While current assistive technology offers solutions for accessing simple text-based content through screen reader software and single-line braille readers, the accessibility of graphical information remains limited. Graphical elements such as images, graphs, tables, flow charts, formulas, web pages, and floor plans pose significant barriers for individuals with BVI. While tactile printed graphics combined with audio descriptions have been employed, they fall short when presented with complex graphical data that involves numerous elements or dynamic real-time interactions. Addressing these limitations is crucial to fostering equal access and promoting inclusiveness for individuals with BVI in our increasingly visual society.

Emerging technologies have made significant strides in addressing the challenge of providing access to 2D information for individuals with visual impairments (BVI). Tactile graphic readers, coupled with 2D pin-matrix displays, have emerged as promising solutions. Tactile graphic readers integrate tactile information through swell and braille paper with audio feedback, allowing for a dynamic representation of information. In contrast, 2D pin-matrix braille readers combine audio feedback with a grid of refreshable tactile pins distributed over a two-dimensional surface. These technologies have garnered considerable attention, particularly in developing mechanisms for raising and lowering tactile pins (1, 2). However, despite these advancements, there are still numerous obstacles and user interface challenges to overcome, such as the Midas touch effect, information overload, and audio-tactile synthesis representation (3–7). These challenges highlight the ongoing need for dedicated research and development in audio-tactile user interfaces, aiming to enhance the accessibility of 2D information for individuals with BVI.

The pursuit of optimal user interfaces for tactile graphics readers is confronted with a range of intricate and intriguing challenges. Such a significant challenge is assisting individuals with BVI in pinpointing elements on 2D tactile surfaces. This task is of great importance as it allows users to find the starting position of a graphic or engage in focused exploration by locating specific elements or areas within the graphic. However, the task becomes notably demanding when employing audio-tactile user interfaces with large surface sizes. The broader range of possible fingertip positions on these expansive surfaces makes it more challenging for users to pinpoint desired positions and elements precisely. Traditionally, users have relied on the assistance of sighted individuals who guide their fingertips to the desired positions on the tactile surface. However, this approach diminishes the independence of using the technology autonomously. Without sighted assistance, users often resort to the trial-and-error method, consisting of exploring each element individually through tactile textures and audio descriptions. While this strategy fosters free exploration and user autonomy, it becomes difficult to apply in scenarios involving complex graphics with a large number of elements. In such cases, locating a specific element or detail within the information cluster requires significant time and effort, ceasing efficient information retrieval.

Extensive research has delved into diverse methods aiding individuals with BVI in pinpointing elements on tactile surfaces. Beyond the trial-and-error approach, these encompass sonification, speech, and haptic feedback. We conducted an in-depth literature review to understand how individuals with BVI have employed these methods and to explore their main advantages and applications. Since tactile graphic readers are still emerging with limited contributions, our analysis extends to encompass all technologies that deliver graphical information to people with BVI.

1.1 Trial and error

Arguably, the trial-and-error strategy is the most common method for people with BVI to locate elements on tactile surfaces. Users explore graphic elements individually until they find the desired element, building a mental representation of the content. On touch screens, users explore elements through speech descriptions (8, 9) or vibration feedback (10). In 2D tactile readers and 3D models, users explore through audio descriptions and braille labels (11–21). This approach supports free exploration but lacks guidance for locating all elements. People with BVI have highlighted the need for an assistive interface to pinpoint elements on tactile surfaces (9, 20–24).

1.2 Sonification based

A sonification-based user interface uses sound processing, including tone frequency and gain changes, to guide users to a specific location on a 2D plan. Inspired by the typical car parking aid, one strategy is to use one fixed background sound and increase its frequency as the user gets closer to the target (25). This technology is familiar to users with BVI since it is used in other aid technologies (26, 27) including pinpointing a target rotation direction (28, 29), aiming a camera to the correct angle (30) or for learning line shapes (31). Some strategies use different sounds to map the X and Y axis positions (23). Similar to the car parking aid, the closer the user gets to the correct X or Y position of the target, the higher the frequency of the sound mapped to that axis. While this strategy has the potential to give more details about the target location, it requires that users move their hands in a straight line through the axis, which is a difficult task for people with BVI (22). It is also a common sonification-based strategy in assistive technology for the BVI to create a background that delineates the exact x and y position of the user (32). This aid does not directly guide the user to one element but helps contextualise the user's current position. Another strategy is to associate a sound with each element on a graphic. The audio is played when the user approaches one of the

elements. This approach can also be used with 3D spatial audio, substantially increasing the perception of closer elements (33). Nevertheless, for graphics with many details, the user would be overloaded with multiple sounds from several elements, rendering this approach unreliable for complex graphics.

1.3 Speech based

Speech-based strategies use speech instructions such as the cardinal directions or the clock system to guide the user's hand to a specific position on the tactile surface. Cardinal directions speech strategy uses (top, bottom, left, and right) instructions to guide people with BVI to a specific position on large 2D surfaces. This strategy has been used in touch screens and tactile graphic readers (22, 34), but it is also common in other technological contexts (24, 30, 35, 36). More refined approaches extend beyond directional cues, incorporating proximity feedback through volume adjustment (22) or subtle modifications to speech instructions, such as using "go a little left" instead of "go left" when the user is close in proximity (21). The clock direction system is an alternative to the cardinal system (3 *o'clock*, 6 *o'clock*, 9 *o'clock and* 12 *o'clock*). Some interfaces extend beyond the typical 4-directions to utilise a 12-direction system, providing superior precision in directional guidance, as successfully implemented in technologies such as BlindSquare (37). In (38), the authors concluded that BVI people prefer the clock system to voice instructions when locating elements in indoor floor plans. For others, it is a matter of personalising (39, 40). Some users prefer a clock system, while others prefer voice instructions of the cardinal directions, as some prefer faster and others prefer regular text-to-speech audio speeds (27). Nevertheless, clock system interfaces are common in assistive technology for BVI users (41). Previous research has shown that voice guidance helps BVI people pinpoint and target elements effectively. However, users revealed dissatisfaction with the repetitive and potentially irritating nature of using voice-based feedback (22, 24, 35, 38, 39).

1.4 Haptic based

Beyond audio-based strategies, some have used haptic feedback to assist people with BVI in pinpointing elements in tactile surfaces, including extra markers and cutouts, additional wearable tools, and representation changes on the tactile surface. Additional hardware like 3D-printed textural overlays provides quick access but requires replacement if elements move (42). Dynamic magnetic markers offer guidance but lack precision (43). The HyperBraille project's pin-blinking UI highlights elements but needs a high refresh rate not supported by most 2D pin-matrix readers (44–47). These methods facilitate pinpointing but do not wholly guide the user's fingertip to the target position. Hand-wearable interfaces offer haptic feedback but negatively affect haptic sensitivity and restrict tactile contextualisation (48–53). Movable guide sliders like the Graille 2D braille display offer precise positioning but limit tactile interaction due to single-finger use (54). 2D refreshable pin-matrix displays, such as those from the HyperBraille project, provide zooming-panning operations that facilitate the location of elements but do not fully guide the user's finger to the target element (55, 56). Overall, using additional hardware and wearable interfaces to assist people with BVI in pinpointing elements on tactile graphics is not a scalable strategy, working exclusively on the devices that implement each additional hardware. For this reason, we did not develop a solution of this kind in this paper since we were looking for a solution that could be extendable to a more extensive set of technologies (tactile graphic readers, touchscreens, and 2D pin-matrix displays).

Despite the significant number of approaches developed thus far, a standardised solution for pinpointing elements in 2D tactile graphic readers has yet to be established. A sound-based approach seems to be the best option for effective and scalable use in this family of assistive technology. Past research (22) has revealed that a Voice-based is more efficient and effective in assisting users in pinpointing elements in tactile graphics readers. Still, sonification solutions have been considered beneficial in other applications for BVI (29, 57–60). Moreover, combining the advantages of the two approaches is possible, potentially leading to performance benefits. By addressing these issues, the current study aims to contribute to the ongoing discussion on which sound-based approach is the most efficient for pinpointing elements of 2D data.

In this investigation, we address the limitation of element pinpointing within tactile graphics and further investigate potential solutions through a user-centred design approach, closely collaborating with BVI employees from Inventivio GmbH. This collaboration effort led to the development of three unique navigation user interfaces, with two adopting state-of-the-art approaches (Sonar and Voice) and introducing an entirely novel approach (Sonoice). Sonar UI is based on proximity-radar sonification navigation, the Voice UI utilises direct speech instructions with clock-system commands, and the Sonoice UI combines sonification with voice feedback. These UIs were carefully designed to improve the accuracy and efficiency of pinpointing elements, specifically tailored to meet the needs of individuals with BVI. The design choices were based on the widespread adoption of sonification and speech-based UIs in assistive technology, facilitating enhanced access to tactile graphics as supported by relevant studies (9, 22, 34, 50, 61, 62).

Building upon this foundation, our study conducted a comprehensive comparison of the new Sonoice UI with two other previously established audio-based UIs (Sonar and Voice) and the trial-and-error strategy, serving as the baseline benchmark. The Sonoice UI strategy could have been expected to be the most efficient and satisfying method overall as it aims to combine the advantages of the Voice and Sonar UIs. Although the primary objective is the performance of the Sonoice UI, we keep the analysis open and unbiased, i.e., perform a general comparison of all strategies. Thus, we investigate whether these UIs could surpass the trial-and-error approach in effectively guiding users to their desired location. By pursuing this line of inquiry, we aimed to gain invaluable insights into the impact of all user interface strategies, whether they would be more effective in guiding the user to the

target location, and recognise the potential complexities that could arise from integrating multiple signals.

2 Materials and methods

2.1 Participants

The study involved ten participants, four females and six males, who were visually impaired or blind. Participants were recruited from Osnabrück city and its surrounding metropolitan region in north-western Germany. The recruitment process involved close collaboration with the local Lower Saxony blind association BVN, which included distributing accessible documents and featuring an audio segment about our study in their newsletter. Interested individuals who responded to the segment via email were then sent additional information and subsequently participated in the study. Only those who reported a medical diagnosis of visual impairment or blindness were included in the study, as we did not measure visual acuity directly. The University of Osnabrück ethics committee approved the study protocol before recruitment, and informed consent was obtained from all participants after they were briefed about the study's nature.

While the number of participants does not yet allow for a rigorous statistical analysis of visual impairment subgroups, we have categorised and recorded the results at this level to enable future meta-analyses incorporating data from diverse studies. Based on self-reports, two participants were grouped as congenitally blind (CB), five as late blind (LB), and three as visually impaired (VI) (see Table 1).

Exclusion criteria involved age (under 18), current or past substance abuse, and medical abnormalities that could interfere with the aim of the study, such as those impacting cognitive functions, the sense of touch, hearing or communication disorders, or the motor system. The inclusion criteria for the study involved participants with either an English or German language background. Study materials were provided in both languages as accessible documents or audio recordings. Additionally, none of the participants had hearing or communication disorders.

Due to their "low representation in the general population and mobility difficulties" (64), recruiting participants with BVI for user studies can be a challenging task (33, 58, 65–68). As a result, the number of BVI participants in this study was relatively small. However, involving users and conducting multiple usability tests to follow a user-centred design methodology is crucial. While the small sample size is a limitation, it marks a positive step forward, paving the way for more extensive studies in the future.

2.2 Materials

The developed pinpoint strategies were tested and implemented on the Tactonom Reader (Inventivio GmbH) (69), a 5.3 kg tactile graphic reader with a 29 cm by 43 cm magnetic metallic surface (Figure 1). This device integrates tactile graphics (swell or braille paper) with audio explanations, using an RGB camera to detect a QR code that links to an SVG file containing shape elements (*<line>*, *<rect>*, *<circle>*, and *<path>*) and corresponding audio labels. Four corner markers map the SVG elements to the tactile paper on the metallic surface. Fingertip detection via the RGB camera allows users to access audio information by pinpointing graphic elements. Additional details on the Tactonom Reader are in (22, 69). This study used version 2.5.0, released in March 2023.

We implemented the pinpoint strategies on the Tactonom Reader using graphics from the open-source Problind database (70), which contains over 3,000 compatible SVG graphics across various contexts, including education, geology, biology, chemistry, mathematics, music, entertainment, and floor plans. For this study, we used four graphics from the Problind database for context exploration and designed eight new SVG graphics for the testing session, all following the Problind layout (Figure 2).

To assist users in understanding and learning the pinpoint navigation strategies, we used four original graphics from the Problind database: *Deutschland*, *Osnabrück District*, *La France*, and *United States of America*, each in their distinct language (German, French, and English). *Deutschland* and *Osnabrück District* were included to offer users familiarity with their regional context. *La France* and *United States of America* were chosen for their popularity and to provide diverse, engaging perspectives while showcasing the customisation and scalability of the Problind database (70). As users with BVI have shown interest in map representations in past studies (22, 71, 72), these

TABLE 1 Demographic Data of Participants (P1-P10).

Users	Age range	Gender	VI type	VA level	Experience with 2D UIs
P1	65+	Male	VI: visually impaired	<6/60	No
P2	65+	Male	LB: late blind	<3/60	Navigation aids, braille display
P3	45–64	Female	LB: late blind	<3/60	Navigation aids
P4	45–64	Male	LB: late blind	<3/60	Navigation aids, PC interfaces
P5	65+	Female	LB: late blind	<3/60	No
P6	45–64	Male	VI: visually impaired	<6/60	No
P7	18–45	Female	CB: congenitally blind	<3/60	Applications, visual-tactile aids
P8	18–45	Male	CB: congenitally blind	<3/60	Various navigation UIs
P9	65+	Female	LB: late blind	<3/60	No
P10	45–64	Male	VI: visually impaired	<6/60	Navigation and accessibility UIs

Visual acuity (VA) levels defined by the WHO (63).

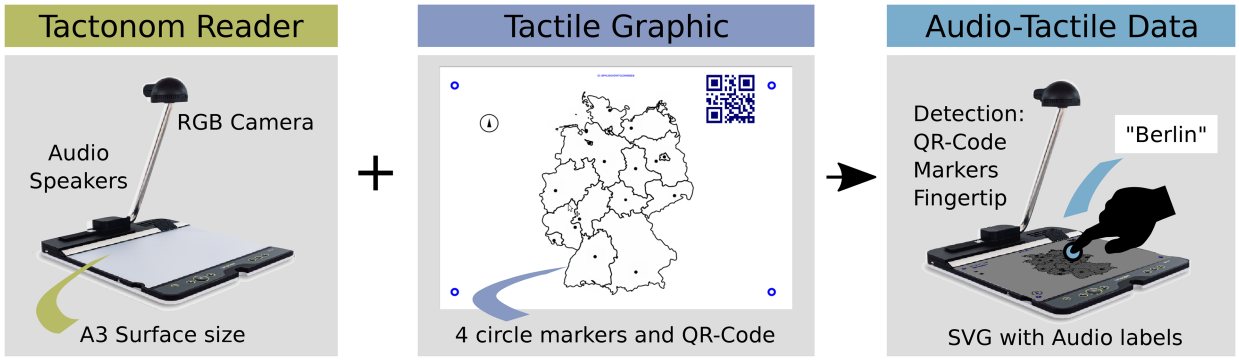

FIGURE 1
The Tactonom Reader 2.5.0v workflow.

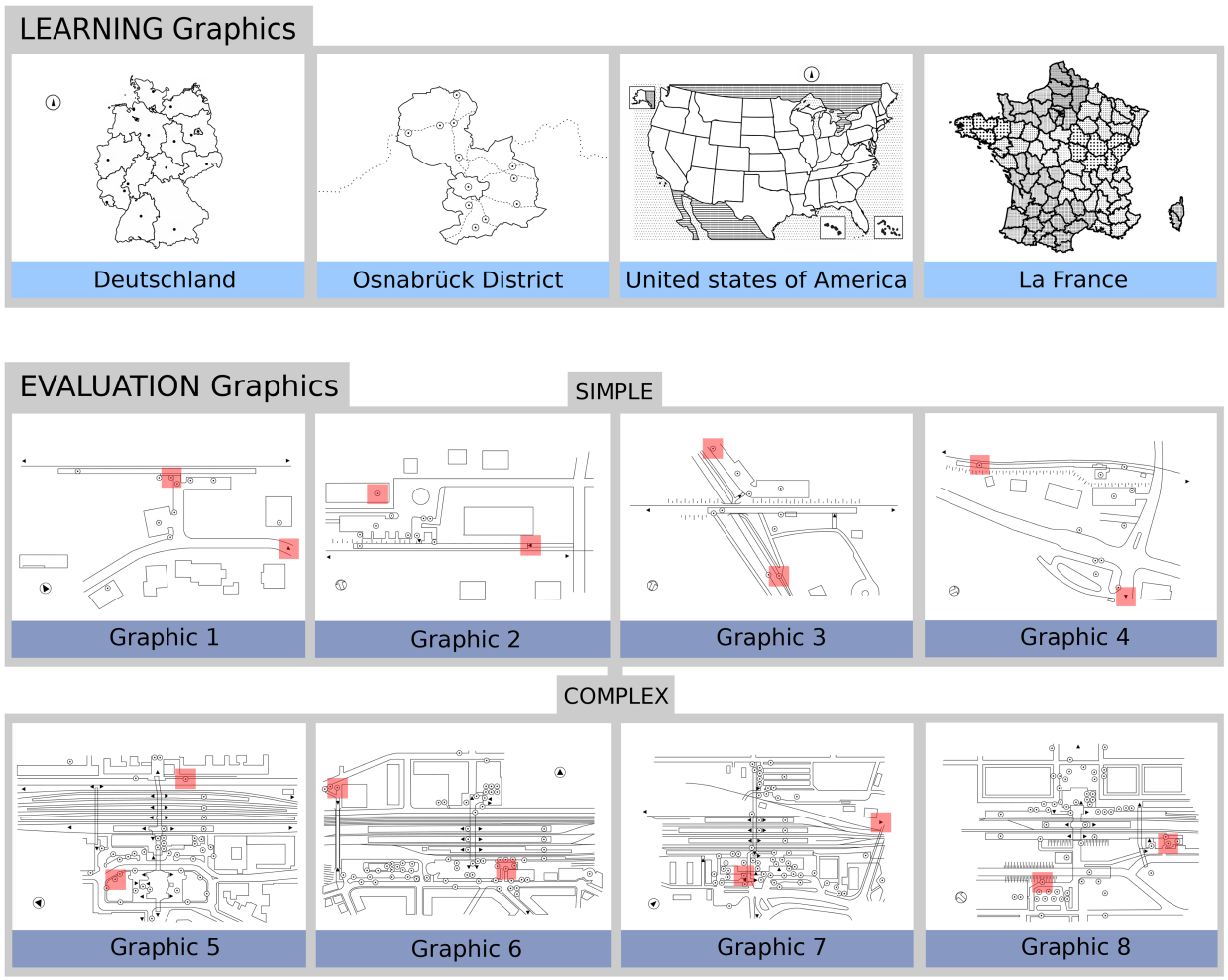

FIGURE 2
Graphics used to assist participant learning (top) and evaluate the pinpoint navigation strategies (bottom) in this study. The red squares demarcate the target elements participants were required to locate on the evaluation graphics during the testing session. These squares were enlarged to three times their original size to facilitate ease of viewing. For clarity, the blue targets and QR code from the Problind database layout have been intentionally omitted from this figure.

graphics were selected to make the interaction and user-interface learning more engaging for participants.

To evaluate the pinpoint navigation strategies, we designed eight graphics representing train station floor plans across Germany, graphics 1 to 8. These are split into two categories: simple train stations and complex train stations. This complexity is expressed by the total number of spot elements, which are small circles and triangles SVG shapes with a square annotation area of 10 mm by 10 mm. The annotation demarcates the region where the fingertip must be positioned to access the additional information. Graphic 1 to 4 are simple train stations with an average number of 14 spot elements per graphic. Graphic 5 to 8 are complex train stations with an average number of 79 spot elements per graphic. Within the spot elements of each graphic, two elements were assigned as the target elements that the user will have to pinpoint in the evaluation session. Beyond the spot elements, the train stations include audio labels on the platforms, train tracks, streets, and outside buildings. The spot elements annotations themselves demarcate points of interest in the train station, including entrances, elevators, bus stops, cafes, information points, bicycle parks, and others. We used train station representations since train stations are among the most visited places by people with BVI (72, 73), and mobility and orientation applications are not as developed as other fields in this emerging technology (7). We designed these graphics and added audio labels using the open-source software *Inkscape* on an SVG blank page with the Problind layout. All SVG elements were rendered in black with a stroke width of 0.5 mm. The completed SVG graphics were uploaded to the database, printed on swell paper, and processed through the PIAF (*Tactile Image Maker*) heating chamber (74). All learning and evaluation graphics used in this study are shown in Figure 2.

2.3 Pinpoint navigation strategies

We explored four pinpoint navigation strategies: Trial-and-Error, Sonar, Voice, and Sonoice (Figure 3). These were implemented on the Tactonom Reader using the MINIM audio processing library version 2.2.2, which handles real-time adjustments in volume, pitch, and panning (75). Our experiments utilised a 100 by 100 digital space to map the user's fingertip and target location, ensuring consistent audio behaviour across different surface sizes. This digital space allows our audio strategies to be applied to various devices by converting any two-dimensional space accordingly.

Individuals with visual impairments often rely on **trial-and-error** to locate elements on tactile surfaces. This involves exploring each interactive element on a surface one by one until the target element is found. In the context of the Tactonom

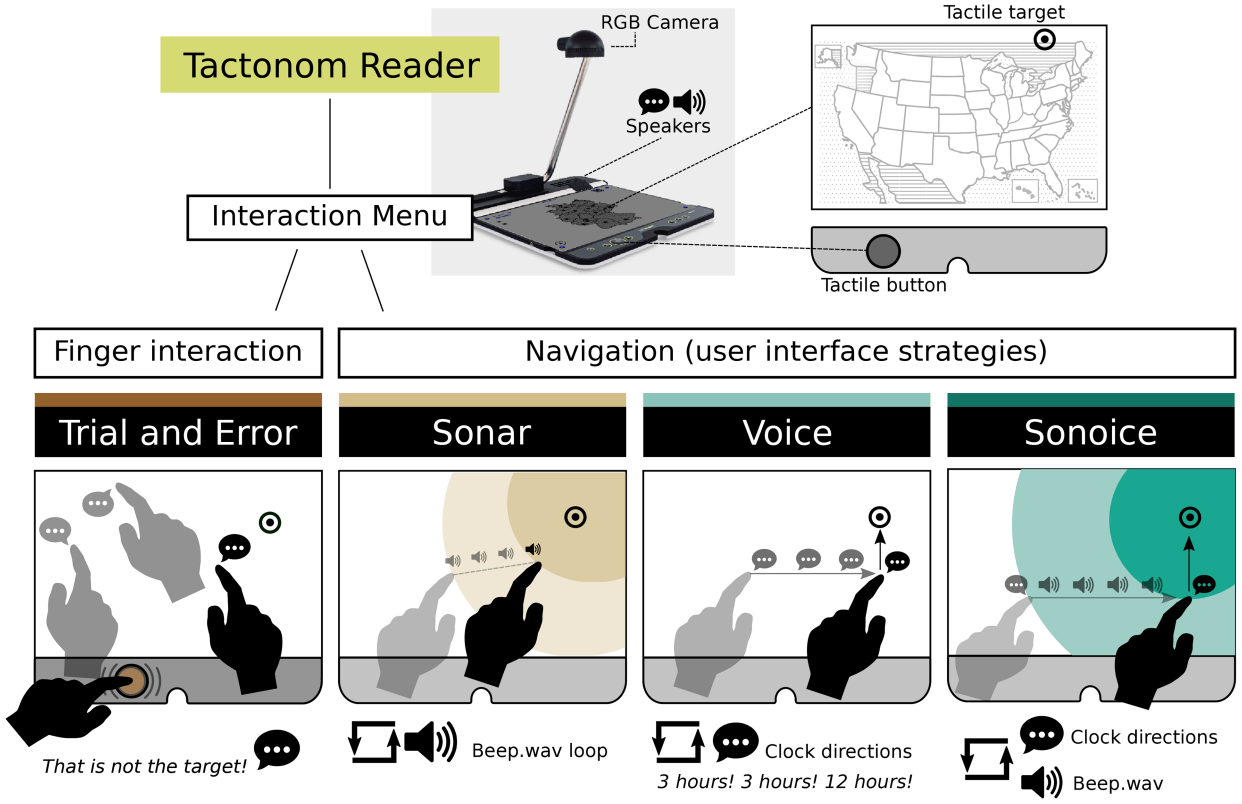

FIGURE 3
Pinpoint Navigation Strategies for Tactile Graphics (trial-and-error, Sonar, Voice, and Sonoice). The figure presents the workflow and key components of the four navigation strategies used in our study for element pinpointing in tactile graphics. Each strategy is illustrated with a diagram depicting the user's interaction and associated audio cues.

Reader device, the user can access the information using a combination of hand gestures. Specifically, one hand presses a button while the other serves as a cursor indicator on a 2D tactile graphic. Every time a user queries an element, the device provides audio feedback to indicate the information associated with the element. This information is presented in an audio format, such as text-to-speech or sound. Exploring tactile graphics with a simple button press interface and audio feedback helps to minimise cognitive load and maximise accessibility for individuals with BVI.

Sonification, specifically the **Sonar pinpoint navigation**, is an alternative to the trial-and-error approach for locating elements on tactile surfaces. This strategy draws inspiration from submarine sound navigation and leverages audio feedback to guide users in locating target elements. A background beep sound with a frequency of 412.150 Hz is used to provide auditory feedback, with the frequency and volume of the sound increasing as the user's fingertip gets closer to the target element. While Sonar navigation had previously been implemented in the Tactonom Reader and introduced in prior research (22), user-centred design has led to significant new improvements to meet user's needs. We use a linear regression function $y = mx + b$, where $m = -0.0217$ and $b = 2.89$ to quantify the magnitude of frequency variation in the beep sound. In this equation, x represents the distance between the user's fingertip position and the target element in the 100×100 digital space, while y represents the frequency increase of the beep sound relative to its baseline frequency of 412.150 Hz. As the user approaches the target element, the frequency of the beep sound increases. For a distance of 0 in the digital space, indicating that the user's fingertip has precisely reached the target element, the frequency increase reaches its maximum value of 2.89, corresponding to a frequency of 1,191 Hz (2.89×412.150 Hz). The background beep sound has a duration of 0.22 s and is played in a loop while the Sonar navigation is active. All the duration and frequency value adjustments were fine-tuned during user-centred design testing with BVI individuals at Inventivio GmbH.

While sonification is a popular technique for tactile navigation, **Voice pinpoint navigation** offers an alternative method for guiding users towards their target element. This technique involves delivering verbal instructions to the user, indicating the direction of the target element in relation to their fingertip position. Our past research and user-centred design have already looked at voice navigation, where we concluded that direction voices such as "top" and "bottom" caused ambiguity and confusion regarding whether to interpret these cues in a 2D or 3D context (22). Consequently, we implemented a novel variation of Voice navigation, incorporating the clock system, which specifies directions as "3 o'clock," "6 o'clock," "9 o'clock," and "12 o'clock". Although some successful navigation technologies use additional clock directions like "2 o'clock" or "5 o'clock" (37), we deliberately excluded these from our voice UI, and chose to prioritise simplicity and familiarity, aligning it more closely with the majority of the clock-speech guidance systems used in our context (38–41). While additional directions offer increased precision, they come with the drawback of added processing time and still require micro-adjustments. Past research has concluded that BVI individuals have difficulties pinpointing elements in a straight line along vertical and horizontal directions (22), making diagonal movement potentially more confusing and less efficient for them. The Minim audio library is utilised to adjust the volume of the voice instructions and pan the sound in stereo as the user approaches the target element, providing additional auditory feedback. The specific voice command played is determined based on the biggest distance between the user's fingertip and the target element. This ensures the voice feedback is consistent and reliable, regardless of the user's specific starting position on the tactile surface. We used German clock system voices to meet the needs of German-speaking participants in this study.

Following a user-centred design approach to enhance pinpoint navigation speed and user satisfaction, we have developed a novel strategy called **Sonoice** (sonar + voice) that combines sonification and voice pinpoint navigation. Sonoice begins with a single voice direction instruction using the clock system, followed by a continuous loop of a beep sound. The voice direction is determined by the largest distance to the target element, be it vertically (12 or 6 o'clock) or horizontally (3 or 9 o'clock) oriented. As the user approaches the target, the volume and frequency of the beep sound dynamically adjust following the same linear regression function employed in the Sonar navigation strategy. This continues until the user reaches the target element's x or y threshold based on the voice instruction. For the direction voices "3 o'clock" and "9 o'clock", this threshold is the x position, while for the voices "6 o'clock" and "12 o'clock", it is the y position. When the user reaches the threshold, a trigger sound plays and a new voice instruction is given to guide the user towards the target element. Once again, a background beep sound starts playing in a loop until the user reaches the target's x or y threshold. To enhance user guidance, the Sonoice strategy incorporates a wrong-direction feedback mechanism. If the user moves in the opposite direction of the previous voice instruction, the system replays the last instruction to provide corrective feedback. In addition to addressing the issue of moving the fingertip in a straight direction, which was present in the previous study (22), the Sonoice method offers further usefulness. By continuously giving new voice instructions at each x or y threshold of the target element, the method ensures that the user is always directed towards the target. Additionally, if the user stays still for over 3 s, a new voice instruction is triggered based on the larger distance to the target element. Overall, the Sonoice method attempts to integrate the benefits of both sonar and voice pinpointing strategies, offering a comprehensive and novel approach to tactile surface navigation.

When users lift their hand off the tactile surface of the Tactonom Reader, causing it to go out of view of the camera, the audio feedback is immediately silenced, regardless of the current pinpoint navigation strategy. Upon reaching the target, the system plays a sound to indicate success, "*success.wav*", and all navigation sounds are stopped and turned off. The stereo sound distribution is enabled for all pinpoint strategies, but

due to the Tactonom Reader's speaker placement, the panning effect may not be noticeable. The Tactonom Reader does not play any other embedded digital audio information during navigation. All methods operate at a 10 FPS rate, corresponding to the RGB camera's fingertip detection speed, enabling real-time interaction.

2.4 Procedure and design

We employed a within-subjects design for the study, where each participant was randomly assigned to test all four pinpoint strategies. The tests were conducted individually in a single 90-min session for each participant. Figure 4 illustrates the step-by-step progression of the experimental procedure, ensuring clarity and enhancing comprehension of the distinct phases involved.

2.4.1 Preparation

At the beginning of the study, the participants were given a detailed explanation of the study's purpose and procedures. They were then asked to provide their consent either by signing a consent form or providing a verbal agreement, which was audio recorded. Participants were informed that they could stop the experiment at any time without giving any reason. This phase lasted for 15 min.

2.4.2 Exploration

Subsequently, the exploration phase started, and participants received fifteen minutes to explore the Tactonom Reader with their hands. Beyond getting used to the device dimensions and creating a mental image, participants were allowed to interact with the learning graphics (Figure 2) to understand the Tactonom Reader workflow.

2.4.3 Training

Following the exploration phase, participants underwent a training phase where they learned the four pinpoint strategies implemented on the Tactonom Reader. The training phase began with placing one of the learning graphics on the device. During this phase, participants were instructed to learn all four pinpoint strategies: trial-and-error, Sonar-based, Voice-based, and Sonoice. After selecting an element target from the learning graphic, participants pressed the "enter" button, and a "beep" sound marked the start of the trial. Participants then used the selected strategy to pinpoint the target. They were allowed to repeat the training trials several times for a maximum duration of five minutes per pinpoint strategy.

2.4.4 Testing

After receiving instructions and confirming their understanding of the experimental procedure, participants

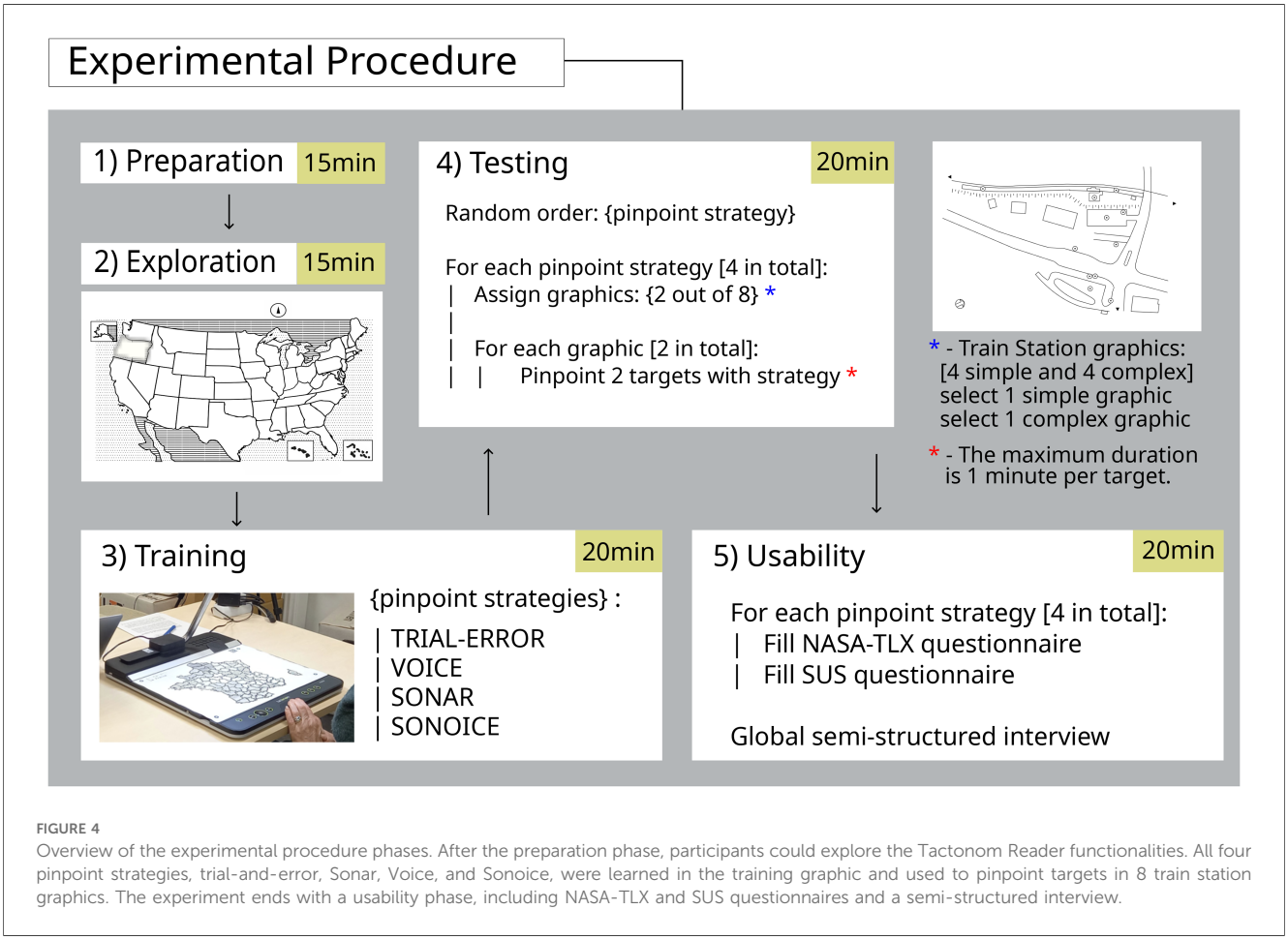

FIGURE 4
Overview of the experimental procedure phases. After the preparation phase, participants could explore the Tactonom Reader functionalities. All four pinpoint strategies, trial-and-error, Sonar, Voice, and Sonoice, were learned in the training graphic and used to pinpoint targets in 8 train station graphics. The experiment ends with a usability phase, including NASA-TLX and SUS questionnaires and a semi-structured interview.

entered the main experiment phase, the testing phase. Randomly selected by a computer script, one of the four pinpoint strategies and two train station floor plans (one simple and one complex) were presented to the participants. The chosen pinpoint strategy was introduced and displayed on the Tactonom Reader, and the first graphic was placed on the device. Once participants were ready, they initiated the first trial by selecting the navigation mode through the main menu. A target element was randomly assigned from two options, and its name was announced. After a "beep" sound, participants navigated to the correct target location using acoustic feedback from a navigation UI or trial-and-error strategy. After successfully pinpointing the target element, a "beep" sound marked the end of the trial. Each trial had a duration limit of 60 s. If the participant did not successfully pinpoint the target within the allocated time, a "timeout" sound would mark the end of the trial. The participant was instructed to repeat the same procedure for the remaining target element of the current graphic. Once all target elements in the current graphic were located, the second train station floor plan was presented on the Tactonom Reader. The participant then finds two targets on the second graphic using the same strategy. This procedure was then repeated for the other three pinpoint strategies, with their order randomised to eliminate any potential bias. To provide participants with flexibility in using their preferred strategies, they were instructed to place their index finger anywhere on the surface of the Tactonom Reader. The initial position was intentionally not fixed to allow participants the freedom to navigate as they preferred.

2.4.5 Usability

The final part of the experiment involved a NASA-TLX (76) and SUS (77) questionnaire for each pinpoint strategy and an interview that aimed to assess the participants' user experience. More specifically, it aimed to assess the usability of the Tactonom reader and evaluate how practical the different pinpoint strategies were in guiding a blind or visually impaired user to a particular element in tactile graphics. As we additionally tried to answer the question of what other aspects of the Tactonom Reader and the implemented strategies could be improved, the interview was conducted as a semi-structured interview. This allowed the experimenter to ask additional questions in case the participant reported intriguing observations next to the general questions that were the same for all participants (available in the Supplementary Material).

2.5 Data analysis methods

We employed a mixed-methods approach, integrating both quantitative and qualitative data, including interviews. The analyses of the behavioural data, including UI performance and the impact of graphical complexity, use total trial times as the dependent variable (to assess efficiency), employing parametric statistics (ANOVA) for statistical testing. Questionnaires (NASA-TLX and SUS) are evaluated using standard normalised scores (to assess user satisfaction), while subjective data from interviews and open-ended questions are documented with descriptive statistics and illustrated using original user quotes.

3 Results

Our investigation aimed to assess the efficiency and user satisfaction of four distinct navigation strategies (Figure 3) employed for pinpointing elements in 2D tactile graphics. To accomplish this, we conducted a comprehensive analysis of quantitative and qualitative data obtained during the testing and usability phases, thereby providing a thorough validation of the diverse pinpoint strategies. Although we did not perform further statistical analysis on these subgroups, the results include data categorised into the three types of visual impairment: CB (congenitally blind), LB (late blind), and VI (visually impaired). Henceforth, participants' comments will be accompanied by their identifier, type of visual impairment, and favourite navigation strategy (e.g., P7, CB, Sonar).

The results of our study are presented across four key sections. Section 3.1 compares the efficiency of the four navigation strategies (trial-and-error, Sonar, Voice, and Sonoice). Section 3.2 analyses user satisfaction while using these strategies, and Section 3.3 examines the differences in performance when interacting with simple or complex tactile graphics. Additionally, Section 3.4 investigates the distinct fields and contexts to which these UIs can be applied.

3.1 Efficiency analysis of pinpoint navigation strategies

To conduct a comparative analysis of the four pinpoint navigation strategies (trial-and-error, Sonar, Voice, and Sonoice), we began by examining the distribution of trial duration in seconds for each strategy. The mean elapsed time required by participants to locate the target element was 57.85 ± 8.04 s for trial-and-error, 20.68 ± 8.99 s for Sonar, 17.58 ± 9.50 s for Voice, and 15.48 ± 8.91 s for Sonoice (Figure 5). Notably, among the 40 trials conducted using the trial-and-error approach, only four trials (10%) were successfully completed within the designated time limit of 60 s, while the remaining trials reached the maximum duration allowed (Figure 5).

Employing a repeated measures ANOVA statistical test with $\alpha = 0.05$, we aimed to assess whether there were any significant variations in mean trial durations across different strategies. Our results showed a statistically significant difference between the mean trial durations of the four strategies ($F(3, 27) = 139.5827$, $p < 0.001$). The calculated F-value (139.5827) exceeded the critical F-value (2.9604) for the test, leading us to reject the null hypothesis. These findings indicate a significant difference in the mean trial durations among the four pinpoint navigation strategies.

To determine the specific nature of the differences between the navigation strategies, pairwise t-tests were performed on the average trial duration for each strategy. The results revealed

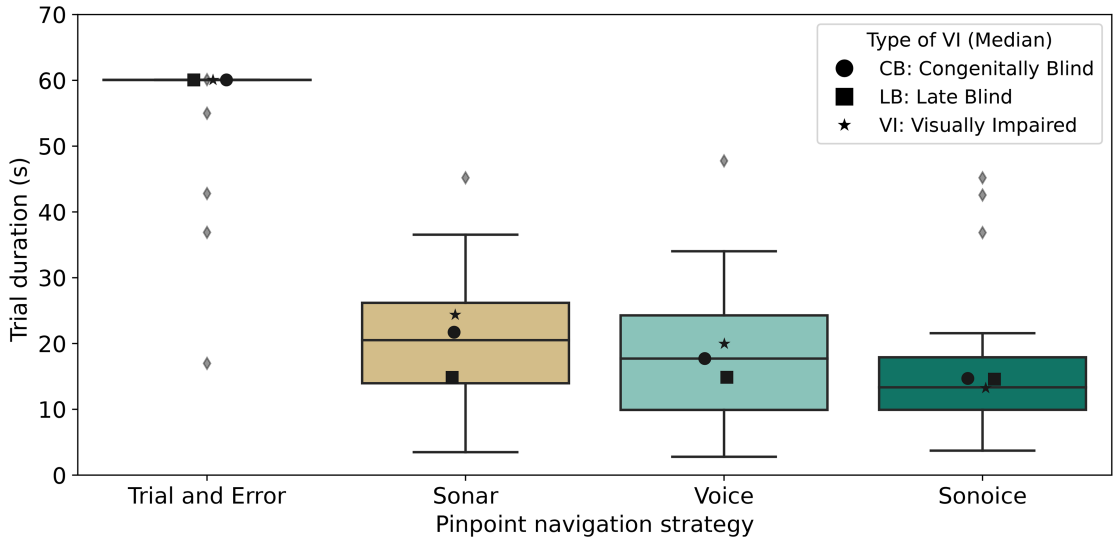

FIGURE 5
Comparison of Pinpoint Navigation Strategies based on trial duration. Boxplots show the distribution of trial durations for each strategy (in seconds), with medians represented as solid lines. Outliers are depicted as grey diamonds. The black markers denote the medians of each subgroup of visual impairment type for each boxplot distribution: circles for *CB*, squares for *LB*, and stars for *VI*.

significant differences between several pairs of strategies. The trial strategy exhibited substantial differences compared to the Sonar ($t = -12.83, p < 0.001$), Voice ($t = -18.00, p < 0.001$), and Sonoice ($t = -22.78, p < 0.001$) strategies, indicating that the trial strategy was significantly less efficient than the other three. However, we found no significant differences between the Sonar and Voice methods ($t = -1.12, p = 0.291$) or between the Voice and Sonoice methods ($t = 1.22, p = 0.255$), or the Sonar and Sonoice methods ($t = -1.95, p = 0.083$).

Interestingly, the Sonoice method exhibited consistently lower mean trial durations than the other strategies, although statistical tests did not yield significant differences. While these findings suggest the potential efficiency of Sonoice in pinpointing elements in tactile graphics, further data would be necessary to determine whether this effect reaches statistical significance.

3.2 User-satisfaction analysis

To assess user satisfaction with the various pinpoint navigation strategies, we employed subjective measures, including NASA-TLX and SUS questionnaires, along with semi-structured interviews.

The NASA-TLX and SUS questionnaires were administered to each participant after they completed the navigation tasks with each strategy. The NASA-TLX questionnaire, measured on a scale of 0 to 100, assesses subjective workload, with lower scores indicating reduced cognitive load. Similarly, the SUS questionnaire, measured on a scale of 0 to 100, evaluates overall satisfaction, with higher scores representing greater user satisfaction. Results from the NASA-TLX questionnaire showed that the mean scores ($\pm$ standard deviation) for the Trial-Error, Sonar, Voice, and Sonoice strategies were 33.67 ± 26.90, 5.50 ± 5.95, 10.00 ± 13.45, and 8.75 ± 9.21, respectively (Figure 6). These results suggest that the trial strategy may have imposed a higher workload on the participants since its average score is at least three times bigger than any other navigation strategy. To understand if there was any significant difference between the user-interface strategies for pinpoint elements (Sonar, Voice, and Sonoice), we performed a repeated measures ANOVA statistical test with $\alpha = 0.05$. Results indicated no substantial disparity in the mean NASA-TLX score across the navigation strategies ($F(2, 18) = 0.394, p = 0.983$), suggesting that these are equally effective regarding overall user workload.

Regarding the SUS questionnaire, results showed that the mean scores ($\pm$ standard deviation) for the Trial-Error, Sonar, Voice, and Sonoice strategies were 59.75 ± 36.39, 88.50 ± 13.95, 84.00 ± 17.96, and 83.25 ± 14.67, respectively (Figure 6). The trial strategy had the lowest mean SUS score, indicating it was the least satisfactory method overall. The other three strategies all received an average score not only above the average (68) but above 80, which is considered a high score by past research (78, 79). These results suggest that participants rated the Sonar strategy as the most satisfactory, followed by the Voice and Sonoice strategies. To determine if there were any significant differences between the user-interface strategies for pinpoint elements (Sonar, Voice, and Sonoice), we performed a repeated measures ANOVA statistical test with $\alpha = 0.05$ on the SUS scores. The results showed no significant difference between the strategies ($F(2, 18) = 0.780$, p-value $= 0.473$).

Although neither NASA-TLX nor SUS questionnaire results showed significant differences between the Sonar, Voice, and Sonoice strategies, it is important to note that these are subjective measures and may not capture all aspects of user satisfaction. Therefore, it is still important to consider the

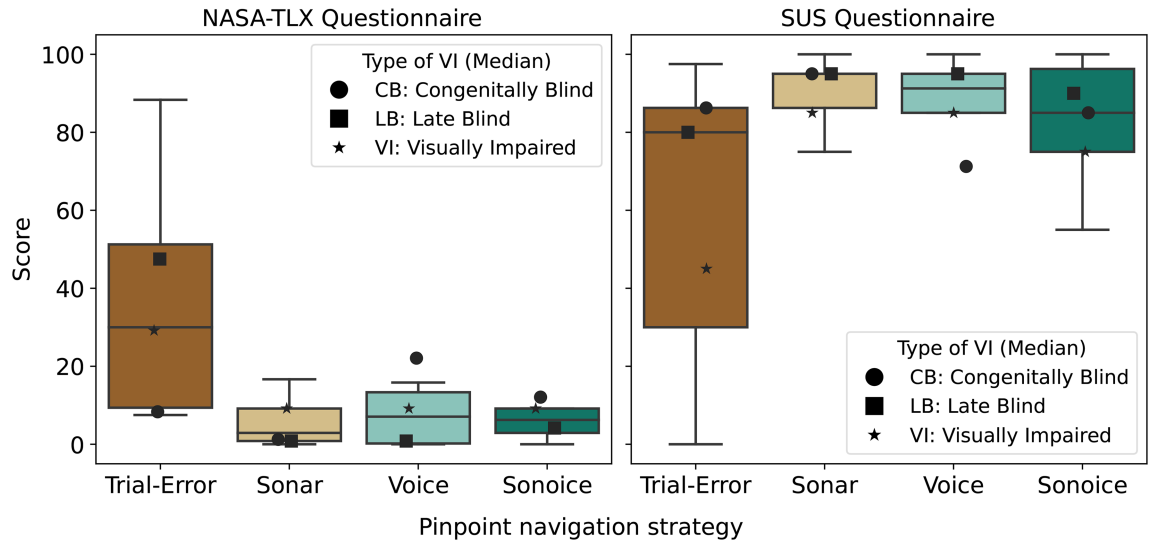

FIGURE 6
Comparison of subjective workload and satisfaction ratings across pinpoint navigation strategies. The left plot shows the NASA-TLX scores, while the right plot shows the SUS scores for the trial, Sonar, Voice, and Sonoice strategies. The black markers represent the medians of each subgroup of visual impairment type for each boxplot distribution: circles for *CB*, squares for *LB*, and stars for *VI*.

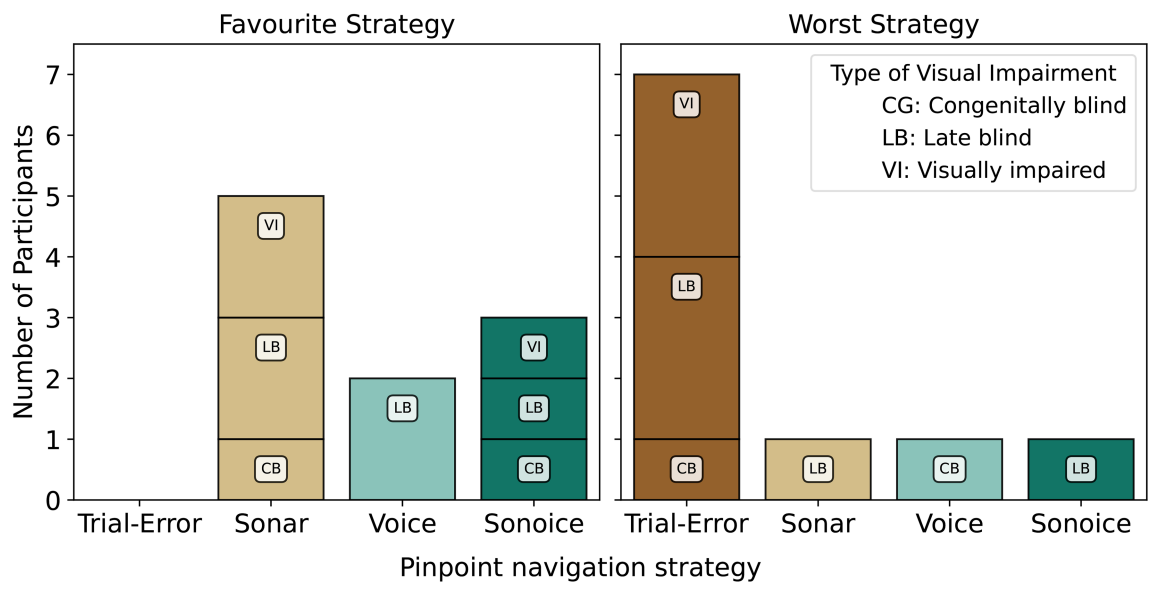

FIGURE 7
Distribution of favourite and worst pinpoint strategies reported by participants (10 in total) during semi-structured interviews. Each bar chart is segmented by the type of visual impairment, denoted by CB, LB, and VI votes.

valuable qualitative feedback obtained from the semi-structured interviews. In the interviews, participants were specifically asked about their most and least favourite strategies for pinpointing elements in tactile graphics (Figure 7). This additional insight allows us to gain a deeper understanding of participants' preferences and experiences with the different pinpoint strategies.

We proceeded to analyze the specific remarks provided during the usability session to acquire further insights not only into the overall subjective evaluation but also to elucidate the underlying rationale behind this decision.

Among the participants, the Sonar interface emerged as the most highly rated strategy, receiving a total of 5 out of 10 votes as the favourite choice (Figure 7). Participants provided positive feedback regarding the Sonar strategy, highlighting its familiarity, responsiveness, and intuitive nature: "*The Sonar because it uses a principle that I am familiar with and it feels more responsive and*

more intuitive" (P7, CB, Sonar), "*Sonar (voices are difficult to hear when there are other people around). It is well distinguishable from natural sounds*"(P10, VI, Sonar), "*Sonar because it is super quick and intuitive!*" (P4, LB, Sonar), "*My favourite was Sonar, but Sonoice is still a great option although it uses a lot of information which can confuse you!*" (P1, VI, Sonar).

The Sonoice user interface was the second most highly rated strategy, receiving 3 out of 10 votes as the favourite choice (Figure 7). Participants recognised the benefits of utilising a combination of sound and voice to obtain more detailed information and accurately pinpoint the target position: "*Sonoice is direct guidance combined with fast guidance. With more information, you get there faster! It depends a bit on how well you're able to multitask, but it has high potential!*" (P6, VI, Sonoice), "*Most of all, Sonoice because it first provides the general direction and then more fine-tuned details!*" (P8, CB, Sonoice), "*Sonoice because you get a much better overview of the environment in general and the spatial relationships.*" (P2, LB, Sonoice).

Additionally, a subset of participants (2 out of 10) preferred the Voice user interface (Figure 7). These participants found the Voice method to be straightforward to use and responsive: "*The Voice method is very specific and straightforward!*" (P3, LB, Voice), "*The Voice since it is directly interpretable and can change quickly.*" (P9, LB, Voice).

Contrarily, the trial-and-error strategy consistently received the least favourite rating, with 7 out of 10 participants expressing dissatisfaction (Figure 7). Feedback regarding the trial strategy highlighted limitations, such as uncertainty, feeling helpless, and tediousness. Participants shared comments like "*Just with trial and error, you are limited! I feel helpless and don't know what to do! It is uncomfortable and feels more like a TOY than a tool.*" (P3, LB, Voice), "*It is tedious to press the button constantly in the trial and error approach*" (P1, VI, Sonar), and "*The trial and error strategy is difficult to apply in the context of finding an element! Requires a lot of time and pressing!*" (P5, LB, Sonar). Despite its drawbacks for pinpointing elements, participants recognised the trial-and-error strategy's usefulness for obtaining an overview of the graphic content, as expressed in statements like "*The worst was trial-and-error to localise but to explore it's amazing! It should be the first step to explore with this mode to get an overview*" (P8, CB, Sonoice) and "*The trial-and-error strategy would be ideal for exploring as part of mobility training!*" (P2, LB, Sonoice).

Each of the remaining three navigation strategies received one vote as the least favourite, with participants pointing out their specific drawbacks (Figure 7). Some participants expressed challenges with the Sonar strategy, mentioning the difficulty in realising they were moving in the wrong direction, "*Sonar was the worst! It took me super long to change directions and to realise when I was going in the wrong direction. I could not react quickly enough to avoid going in the wrong direction.*" (P9, LB, Voice). The Voice strategy was criticised for requiring excessive mental effort in interpreting the clock system, "*Voice is the worst because I needed to think too much about the clock and where the 3 h is located!*" (P7, CB, Sonar). Participants also found the Sonoice strategy overwhelming, as it demanded sustained concentration, "*Sonoice is too much, and concentration is hard to keep!*" (P4, LB, Sonar).

Based on the results of the NASA-TLX, SUS, and semi-structured interviews, the three user interface strategies for pinpointing elements in tactile graphics have demonstrated their usefulness, exhibiting statistically higher satisfaction levels compared to the standard trial-and-error approach. All ten users unanimously agreed that they found at least one of the three navigation pinpoint user interfaces more useful than the trial-and-error method for locating elements in tactile graphics. Furthermore, all participants highly recommended the navigation user interfaces to other individuals with BVI, "*I absolutely prefer the navigation modes, and I think the Tactonom with these would be a great addition to my current devices!*" (P10, VI, Sonar), "*I would use them. I would retrieve much more information from the graphics with the navigation strategies!*" (P8, CB, Sonoice).

Our analysis revealed that while the Sonoice UI received positive feedback from participants, we did not gather sufficient evidence to conclude that it consistently outperformed the other strategies regarding user satisfaction. It is worth noting that participants' preferences and experiences varied across the different navigation strategies, and no significant differences were found in overall user satisfaction between the Sonar, Voice, and Sonoice strategies according to the collected data.

In summary, the findings indicate that the implemented user interfaces significantly improve user satisfaction compared to the traditional trial-and-error approach. Based on these results, we conjecture that these navigation strategies hold a large potential to enhance the accessibility and usability of tactile graphics for individuals with BVI. Further research and larger sample sizes may be necessary to explore potential differences in satisfaction among the various pinpoint navigation strategies in more detail.

3.3 Unveiling the influence of graphic complexity

To fully understand the efficiency of different navigation strategies in tactile graphics, it is important to explore the impact of graphic types on the performance of these navigation strategies. To address this, our comprehensive analysis covered both simple and complex graphics. The analysis aimed to assess the potential disparities in element pinpointing performance between the two graphic types. Surprisingly, the results revealed no significant difference in the mean trial duration between complex graphics (27.10 ± 20.28 s) and simple graphics (28.69 ± 18.86 s) (Figure 8). These findings challenge our initial assumptions and suggest that graphic complexity does not significantly impact the time required for pinpointing elements. Importantly, this lack of difference holds true across the navigation pinpoint user interfaces (Sonar, Voice, and Sonoice) and the trial-and-error approach.

In addition to evaluating the performance of different navigation strategies on simple and complex graphics, we comprehensively analysed the data using a boxplot to visualise

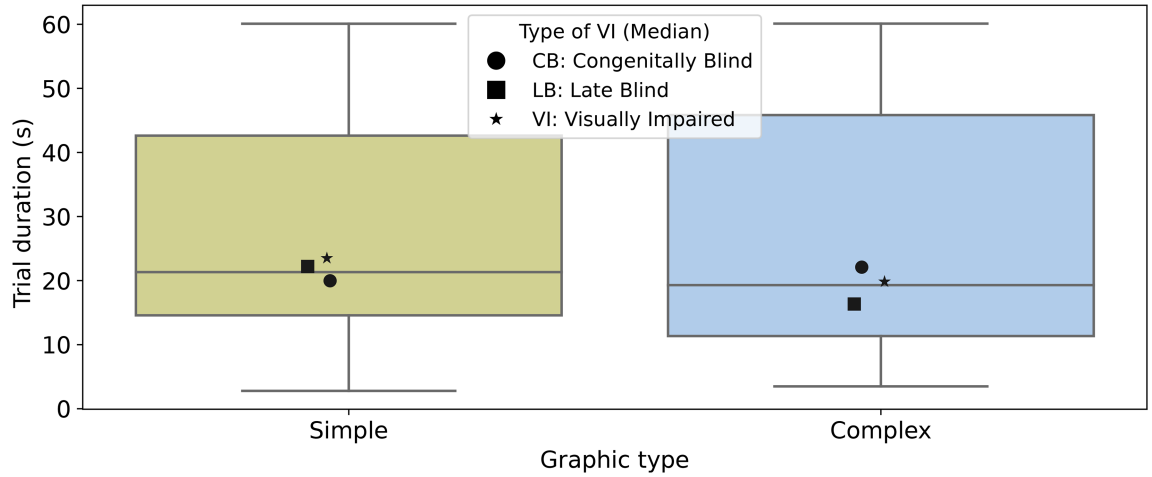

FIGURE 8
Distribution of trial durations (s) per graphic type (Simplex and Complex). The boxplot displays the medians as solid lines. Black markers represent the medians of each subgroup of visual impairment type for each boxplot distribution: circles for *CB*, squares for *LB*, and stars for *VI*.

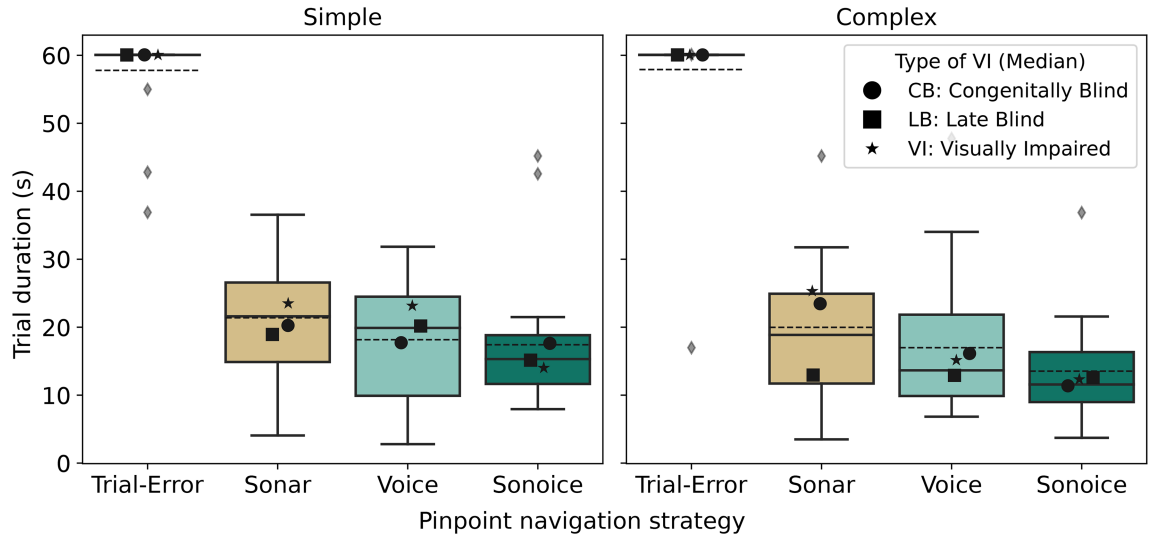

FIGURE 9
Distribution of trial durations (s) across graphic type (Simple and Complex) and pinpoint navigation strategy. The boxplot displays the medians as solid lines, while the dashed lines represent the means. Outliers are depicted as grey diamonds. Black markers represent the medians of each subgroup of type of Visual Impairment (VI) for each boxplot distribution: circles for *CB*, squares for *LB*, and stars for *VI*.

the average trial durations across the graphic type and pinpoint strategy (Figure 9). Subsequently, we aimed to test whether a navigation user interface (UI) allows people with BVI to pinpoint elements in complex graphics more efficiently than the trial-and-error strategy. The results demonstrate the superiority of the Sonar, Voice, and Sonoice navigation strategies over the trial-and-error approach for complex and simple graphics. In complex graphics, the mean trial duration was 19.98 $\pm$ 9.85 s for Sonar, 16.99 $\pm$ 10.39 s for Voice, and 13.53 $\pm$ 7.60 s for Sonoice, while the trial-and-error approach had a significantly higher mean trial duration of 57.91 $\pm$ 9.63 s. Similarly, in simple graphics, the mean trial duration was 21.39 $\pm$ 8.25 s for Sonar, 18.16 $\pm$ 8.75 s for Voice, and 17.42 $\pm$ 9.86 s for Sonoice, compared to 57.79 $\pm$ 6.31 s for the trial-and-error approach (Figure 9).

These findings provide strong empirical evidence that a navigation UI enables individuals with BVI to pinpoint elements in both complex and simple graphics more efficiently compared to the trial-and-error strategy. We interpret these results to suggest that the UIs might be successfully applied beyond complex graphics and underscore their potential to improve

accessibility and usability across a wide range of tactile graphics with varying complexity.

3.4 Expanding applications of pinpoint navigation interfaces

In addition to locating elements in floor plans in tactile graphics, pinpoint navigation strategies offer broader applications. During the semi-structured interviews, participants shared their perspectives on the contextualisation of pinpoint navigation interfaces in various fields of assistive technology. Their comments revealed diverse potential uses, including emergency floor plans, schools, public services, navigation apps like the Seeing AI App, country maps, and even household appliances like washing machines where specific settings can be easily located, "*In floor plans or countries maps. It would be amazing to use it in washing machines and find a certain setting.*" (P5, LB, Sonar). Participants also highlighted the advantage of complementing pinpoint navigation with on-site sensor-based navigation technologies (37, 59, 60, 80) like the FeelSpace naviBelt: "*Use navigation modes for practical preparation and then the FeelSpace belt for mobile applications.*" (P10, VI, Sonar). The idea is to use pinpoint navigation for mobility training, developing mental representations of changing environments, and preparing for visits and trips, followed by on-site navigation aids for real-time assistance.

It was found that 7 out of 10 participants had never interacted with a similar technology beyond the Tactonom Reader device itself, indicating that this technology is still emerging and not readily accessible to users. These subjective evaluations by the users highlight the novel and evolving nature of pinpoint navigation interfaces, underscoring their potential for future applications in various domains and assistive technology.

4 Discussion

Our investigation into the efficiency and user satisfaction of various navigation strategies in tactile graphics has yielded significant insights, contributing to improving tactile information access. Notably, all tested pinpoint user interface strategies outperformed the trial-and-error approach, demonstrating their superiority in facilitating efficient pinpointing of tactile elements. Among these strategies, the Sonoice UI, which combines auditory and voice cues, emerged as the most efficient. However, satisfaction ratings were surprisingly deviant from performing ratings. Participant's feedback shed light on this phenomenon, stating, "*My favourite was Sonar, but Sonoice is still a great option although it uses a lot of information which can confuse you!*" (P1, VI, Sonar), "*Sonoice is too much, and concentration is hard to keep!*" (P4, LB, Sonar). This contrasting perspective adds complexity to the relationship between performance and user satisfaction, emphasising the need for a comprehensive understanding of user preferences and subjective experiences when pinpointing elements in tactile graphics.

4.1 Balancing performance and user satisfaction

Exploring both performance and user satisfaction across all navigation strategies uncovered intriguing insights, defying the conventional notion that the most efficient method would necessarily be the most favoured. Interestingly, except for the trial-and-error approach, which yielded anticipated results, the remaining strategies yielded unexpected outcomes.

4.1.1 High performance

This unexpected divergence was particularly evident in the performance of the Sonoice method. Despite not receiving user satisfaction ratings as high as the Sonar method, the Sonoice method exhibited the lowest mean trial duration during the experiments. This raises the question: how could Sonoice achieve higher efficiency despite slightly lower satisfaction ratings? The answer may reside in the combination of advantages of the Voice and Sonar approaches. The Voice method provides directional guidance but lacks information on the distance to the target and can be confused with natural sounds "*voices are difficult to hear when there are other people around*" (P10, VI, Sonar) (57, 62). On the other hand, the Sonar strategy offers proximity feedback but requires users to interpret pitch sound differences to ensure they are moving in the right direction. With the Sonoice method, we aimed to combine the advantages of both the Sonar and Voice strategies, leveraging their strengths to create a more effective approach. By incorporating directional guidance from the Voice method and proximity feedback from the Sonar method, we sought to provide users with a comprehensive and efficient navigation experience, "*Sonoice is direct guidance combined with fast guidance. With more information, you get there faster!*" (P6, VI, Sonoice). Notably, recent studies have shown that assistive interfaces incorporating both sonification and voice feedback jointly have yielded promising results (28, 40, 81–83), suggesting that combining sonar with voice can possibly enhance the effectiveness of tactile graphics exploration.

4.1.2 High user satisfaction

Although it emerged as the most efficient method, the Sonoice method was not the most preferred strategy during the task. An explanation for this is that Sonoice uses more information than the other two methods, which some users saw as overwhelming, "*My favourite was Sonar, but Sonoice is still a great option although it uses a lot of information which can confuse you!*" (P1, VI, Sonar). Another factor that could have contributed to this may stem from the fact that assistive technology typically relies on either voice or sonification approaches (9, 34, 50, 61, 84), making a combination of these two methods less common and potentially leading to unfamiliarity or hesitation among users.

The theme of familiarity and user preference is further underscored in the case of the Sonar approach. Despite not being the fastest approach, Sonar obtained the highest satisfaction rate, possibly influenced by participants' experiences with assistive technology. Participant comments substantiate this connection, as

seen in statements like "*The Sonar because it uses a principle that I am familiar with*" (P7, CB, Sonar) and "*Sonar because it is super quick and intuitive!*" (P4, LB, Sonar). These findings underscore the influence of participants' prior experiences and contextual factors in shaping their preference for a particular navigation UI, aligning with similar observations in related research (29, 58).

Regardless, it's worth noting that participants received only 5 min of training for each strategy. With extended training, users would potentially become more familiarised and less overwhelmed with the Sonoice approach, changing the results of this investigation. Moreover, these potential changes are also subject to individual differences and the type of visual impairment each participant has.

4.2 The value of the trial and error approach in tactile graphics exploration

While being the least favoured approach and the least efficient in pinpointing elements in tactile graphics, the trial-and-error method still holds value for users. Despite not being ideal for precise element identification, this approach proves to be beneficial for initial exploration and gaining a contextual understanding of the graphic. It allows users with visual impairments to familiarise themselves with the layout and content of the graphic, providing a starting point for further interaction and interpretation. In fact, this method is implemented in other 2D tactile graphic readers (11–18, 20, 23), highlighting its significance in facilitating exploration and providing an overview. As one participant remarked, "*The worst was trial-and-error to localise, but to explore it's amazing! It should be the first step to explore with this mode to get an overview*" (P8, CB, Sonoice) While the trial-and-error method may not provide direct and precise guidance to pinpoint elements, it can contribute to the overall understanding of the two-dimensional information presented.

Given its value in facilitating initial exploration, the trial-and-error functionality should be included in assistive technology for tactile graphics. By recognising its role and benefits, developers can ensure that users with visual impairments can access a range of strategies that cater to different aspects of their exploration needs, enhancing their overall experience and access to 2D information.

4.3 Assessing complexity in train station floor plans

In assessing complexity in train station floor plans, results revealed that the choice of navigation UI strategy (Sonar, Voice, and Sonoice) did not yield significant differences in performance between simple and complex graphics. This indicates that our user interface strategies demonstrated consistent effectiveness regardless of the complexity of the tactile graphic. However, the trial-and-error approach presented a different outcome, as most of the samples reached completion within the given time limit. It is worth considering that if the trial duration had not been restricted to 1 min, we might have observed contrasting results using the trial-and-error method for simple vs. complex graphics. These findings are particularly intriguing, as they shed light on the time-consuming nature of interacting with seemingly "simple" graphics, highlighting the inherent challenge individuals with visual impairments face in accessing and comprehending two-dimensional information (85).

5 Conclusion

The rapid advancements in 2D tactile readers and 2D pin-matrix displays hold immense potential for revolutionising information accessibility for individuals with visual impairments. One crucial aspect of their usability lies in developing effective user interfaces that enhance the precise pinpointing and locating of elements on 2D tactile surfaces, empowering users to access graphical information independently. Our study has unequivocally demonstrated the superiority of an audio-based navigation user interface approach over the conventional trial-and-error method, thereby significantly improving the accessibility of graphical information for individuals with visual impairments. Significantly, our findings unveiled that our user interfaces (Sonar, Voice, and Sonoice) exhibited exceptional performance in terms of efficiency and garnered excellent user satisfaction ratings. Remarkably, these outcomes were achieved even though participants received only a brief 5-min training session, and some had no prior experience with 2D tactile readers. These compelling results not only shed light on the capabilities of sonification/speech navigation user interfaces but also emphasise the importance of user-centred design in creating inclusive technology for the visually impaired population.

Based on the results and discussions of our study, the Sonoice navigation user interface has emerged as a notable solution, achieving higher levels of efficiency compared to the sonar and voice methods. Remarkably, users achieved these impressive results with just 5 min of training, and many of them quickly recognised the potential of Sonoice, interpreting it as "SO NICE!". Interestingly, the most efficient method was not the most favoured one. The simultaneous use of sonification with speech feedback negatively impacted the Sonoice method. A combination of methods that should and partly does outperform the other simpler combinations was not appreciated by all users. Some participants found the Sonoice UI information overwhelming compared to the other navigation user interfaces, which, although slightly slower, still performed greatly. Users are willing to trade off some speed in performance for ease of use and to avoid information overload, interpreting Sonoice more as "SO NOISE!" than "SO NICE!" The choice of using one of three navigation user interfaces is highly influenced by participants' personal preferences and prior experiences. Therefore, understanding individual preferences and tailoring the user interface accordingly is essential for optimising user satisfaction and effectiveness in tactile graphics exploration. In response to these findings, we have integrated all three audio user interfaces,

including Sonar, Voice, and Sonoice, into subsequent software updates of the Tactonom Reader.

Our findings highlight the potential of navigation strategies to enhance the accessibility and usability of tactile graphics for individuals with visual impairments, emphasising the importance of incorporating such user interfaces in future design and development efforts. Moreover, our navigation user interfaces can be extended beyond tactile graphics readers and integrated into various technologies, including tablets and 2D refreshable pin-matrix displays. This broader application of navigation strategies contributes to advancing assistive technology in these emerging devices. As tactile graphics readers and 2D refreshable braille hardware technology continue to grow, it is essential to define optimal user interface standards and expand the capabilities and application domains, further empowering individuals with visual impairments.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by University Osnabrueck Ethics Committee. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

GR: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. VS: Data curation, Formal Analysis, Investigation, Methodology, Resources, Validation, Visualization, Writing – original draft, Writing – review & editing. TS: Supervision, Writing – original draft, Writing – review & editing. RS: Supervision, Writing – original draft, Writing – review & editing. PK: Formal Analysis, Methodology, Supervision, Writing – original draft, Writing – review & editing.

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Conflict of interest

GR is a software engineer at Inventivio GmbH in Germany.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fresc.2024.1368983/full#supplementary-material

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Dehumanizing air travel: a scoping review on accessibility and inclusion of people with disabilities in international airports

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Introduction: Worldwide, one in six individuals live with a disability. Many people continue to experience disabling situations, particularly when travelling. Travel can be an important part of the lives of many people, including people with disabilities. Barriers to accessing air travel can lead to a reluctance to travel for these potential passengers. As early as the flight planning stage, options to facilitate accessibility are limited. At airports, passengers must travel long distances in areas where navigation is complex, and accessibility limited. Furthermore, few aircraft are accessible. The travel experience can have adverse effects on the health of people with disabilities. Practices are sometimes not inclusive, not always available, and may not address the full spectrum of possible needs. The objective of this study is to provide a state of art on accessibility features available to people with disabilities in the busiest international airports.

Methods: A scoping review of practices in airport accessibility was done. A search strategy was deployed in 4 databases (Avery index to architectural periodicals, Medline, CINAHL, and Web of science). The official websites of the 35 busiest airports were exhaustively consulted. All information regarding accessibility measures and inclusive services were extracted.

Results: 31 scientific articles, out of 3,640 screened, and all extracted data from airports' website were considered for synthesis. While efforts are made in major airports, there is a great inconsistency in accessibility features. Both facilitators and challenges are encountered by people with disabilities at every stage of air travel. These stages include journey planning; getting to and from the airport, obtain human assistance, navigate in the premises, check in, security screening, using facilities, boarding and disembarking, customs and immigration procedures, and luggage management.

Discussion: Services need to be extensively planned, placing a significant burden on passengers. The disability-centric perspective disregard passengers' unique needs and capabilities, leading to a sense of dehumanization. The complexity of airport organizations, shared responsibilities, limited communication, training challenges can deter accessibility initiatives and create discomfort during travel. This study is the first step of a broader project supported by Canadian Accessibility Standards, focusing on enhancing inclusive accessibility in Canadian airports.

KEYWORDS

accessibility, airport, inclusive, people with disabilities, participation

1 Introduction

In 2021, approximately one in six person had one or more disabilities leading to disabling situations (1). In Canada, this phenomenon is particularly salient, with more than one in four people living with a disability (2). To address this situation, the Government of Canada proposed several programs and laws focused on equal rights and opportunities for people with disabilities (PwD) (3). Despite this desire for equity, many people still experience disabling situations when carrying out their daily lives, particularly when it comes to travel. Air travel can hold a significant meaning for the social, productive and leisure of everyone, including people living with a disability or disabilities (4, 5).

The many barriers encountered during air travel bring a sense of discrimination and reluctance to travel for PwD (4, 6, 7). From the planning stage onwards, there is no guarantee that the flight provider will be able to accommodate the individual's unique needs. Most airlines offer accessibility information, but the level of detail of the information is insufficient to make an informed decision about travel (8). Often, travellers are forced to contact service providers by phone and give highly personal health information (5, 6). Moreover, few aircraft are accessible. Aircraft configurations and restricted spaces force staff to resort to means perceived as dehumanizing. For example, people in wheelchairs often have to change seats, be manipulated over armrests, board long before other passengers or disembark last. In addition to discomfort and pain, these measures can exacerbate a sense of segregation for these passengers (4, 5). In some cases, boarding staff's perception of a person's degree of autonomy can result in denied boarding, if unaccompanied (5). Other barriers are related to airport facilities. In particular, passengers often have to travel long distances in complex environments. These features can limit PwD' ability to orient themselves and navigate the facilities (5, 7). At many stages, passengers must wait for long periods, in uncomfortable areas, and/or adapted services are scarce (screening, passport, security, etc.). Often, few entertainment options, restaurants or waiting areas are accessible for PwD (6). Airport staff may also lack the knowledge to effectively support specific needs around and within the aircraft (4, 7).

Some airports are trying to mitigate these barriers. In Canada, for example, some airports offer individualized mobility assistance to passengers upon request (9–11). In Toronto, a GPS navigation system with verbal guidance is being tested to improve independence for people with visual impairments (12). Also, a mobile application is available for people with neurodiversity, to guide them step-by-step through the various common procedures at the airport (13). Other services are offered elsewhere. For example, at Hartsfield-Jackson airport in Atlanta, USA, or Haneda International in Tokyo, Japan, quiet areas are available for passengers with developmental, intellectual disabilities or mental health issues (14, 15).

However, while efforts are being made to improve the experience of passengers with disabilities, they can raise other issues. Travel planning is much more important for PwD than for other passengers. Many airport services need to be booked 72–48 h in advance, and there is no guarantee that they will still be available, even after a ticket has been purchased. Passengers must constantly check and anticipate the suitability of the services offered for their specific needs (4, 6, 8). Challenges experienced by passengers with disabilities can lead to adverse effects on physical, psychological and emotional health (4, 5). Indeed, services are often designed according to a specific type of disability (e.g, motor disability, visual impairment), hardly representative of the complexity and diversity of factors that influence the needs that PwD may have (16). This issue is exacerbated by the predominant vision of adaptation rather than inclusiveness in airport accessibility. Indeed, services are primarily aimed at overcoming environmental barriers. These adaptations are not always comfortable or respectful of individual particularities. The systematic use of assistance staff, "segregated" circulation channels and means different from other passengers can create a feeling of marginalization, even humiliation, for passengers with disabilities (5, 7).

Both PwD and airport service stakeholders insist on the importance of developing and updating the measures deployed to improve the experience of passengers living with disability situations. However, it is not very clear what exists today in terms of accessibility practices at international airports around the world. Therefore, the aim of this study is to explore and map existing accessibility and inclusive practices for PwD at international airports, in order to identify gaps and shortcomings.

2 Methods

To address the main objective, a scoping review was carried out through various stages using several methodological guides (17–21).

2.1 Research strategy

The research was developed in order to identify all the scientific literature and grey literature relevant to the research topic.

2.1.1 Scientific literature

A professional librarian, affiliated with Laval University, helped identify the scientific literature relevant to the research question. Her expertise in review methods and specialization in the healthcare field ensured the accuracy, comprehensiveness and relevance of the search. An initial list of keywords and descriptors was identified via eight articles from the preliminary review. The terms were refined and validated by several members of the research team (DG, PhD student; EM and FR, professors). The terminology used for the research is presented in Appendix A. The search strategy was deployed in four databases (Avery's index of architectural periodicals, MEDLINE, CINAHL and Web Of Science). The databases were chosen to reflect the diversity of fields relevant to accessibility and participation: health (CINAHL, Medline), planning and architecture (Avery index of architectural periodicals) and multidisciplinary (Web Of Science). Endnote

software (22) was used to collate all references from the databases. The databases were consulted on November 2, 2022.

2.1.2 Selection of scientific articles

Given the exploratory nature of the scoping review, the criteria did not consider study designs. The selection process was facilitated by Covidence software (23). Covidence is a web-based collaboration software platform that streamlines the production of systematic and other literature reviews. Two members of the research team (DG; JR, research professional) made the initial selection based on titles and abstract. Of the articles selected, they (DG; JR) consulted the full texts to validate the presence of the inclusion and exclusion criteria, presented in Table 1.

2.1.3 Grey literature

At the same time, the websites of the 35 busiest international airports, as well as all Canadian international airports, were consulted. To obtain a list of these airports (Table 2), pre-pandemic air traffic and traffic statistics were used (24, 25). The data available for the pandemic period varies greatly from previous years, given the unequal restrictions on activities between different airports (26). Previous data from the COVID-19 pandemic are therefore more representative of the usual activities of international airports. Each website was consulted in two stages. Firstly, a free manual search was carried out to extract information from sections dealing with services, policies and information on accessibility or inclusion. Then, several keywords, such as "accessibility", "special" or "barrier-free" (see Appendix B) were entered into each website's search engine to obtain data not captured by the first stage. External links to guides or third-party organizations were also considered.

2.2 Data extraction

Extraction was performed according to the methodological specifics of scoping reviews (18). Descriptive data about study design, location, population and context were extracted. The analysis of this data has particular relevance to the object of study, given the diversity of socio-economic, political and cultural influences at different international airports. It helped provide information on the nature and distribution of the studies included (17). Additionally, Bronfenbrenner (27) ecological model's categories, relevant to the object of study (microsystem, mesosystem and macrosystem), were included in the exaction grid (see Appendix C), to ensure that the different levels of contextual factors impacting airports' accessibility were taken into account. Finally, the grid included a section dedicated to the researcher's reflections and notes that may influence the analysis. Two members of the research team (DG, JR) carried out 10% of the extraction, until consensus was reached, to ensure the comprehensiveness and relevance of the extracted data (18).

2.3 Data analysis

Data were subject to thematic content analysis (17, 18, 28–30). This type of analysis is recommended for exploratory studies where data is limited (28, 31). The analysis was carried out using a mixed deductive and inductive approach. Bronfenbrenner (27) model's categories were used to group identified themes and facilitate their analysis (28). Grouping the codes by level of influence has made it easier to identify the main themes, ensuring that they are complementary and mutually exclusive. Identified themes are presented in Table 3. In a subsequent step, the data was linked to the relevant travel stages, to better visualize the traveler's experience over time. Three members of the research team (DG, EM, FR) were involved in data analysis, using Nvivo software (32). Several reduction steps were performed to reduce the number of codes identified and refine the data synthesis.

3 Results

3.1 Scientific articles included

The article selection process is shown in a PRISMA diagram (Figure 1) (33). The database search strategy identified 3,319 unique results. After the selection process, 30 scientific articles were retained for analysis. Systematic reviews were not retained, in order to prioritize first-source literature. The quality of scientific articles was not assessed, and they were not discriminated on the basis of design. The majority of studies were based on qualitative research designs ($n = 20$), while others used quantitative ($n = 7$) or mixed methods ($n = 4$). Table 4 present included studies characteristics and distribution.

3.2 Included grey literature

Table 2 shows all the airports from which the information available on the websites was extracted. Airline web pages were also included when referenced by the selected airport websites.

The desire to support travel opportunities for PwD is not a new topic in airport industry environments. The literature reviewed shows

TABLE 1 Scoping review inclusion and exclusion criteria.

Inclusion criteria	Exclusion criteria
Focuses on people with disabilities or living with handicaps. Relates to accessibility and inclusion. Pertains to measures or studies at airports Aims at effects on participation, accessibility, use, inclusion, desire to travel or suitability of the physical environment.	Is a market analysis Is a statistical analysis of air traffic Pertains only to freight, cargo, military or aerospace personnel Focuses exclusively on the issues and effects of profitability, traffic, equipment, environment or flight management. Other type of publication: advertising, protocol, magazines, books, opinion pieces. Written in a language other than French or English.

TABLE 2 World's and Canada's busiest international airports (Port Authority of New York and New Jersey, 2019; statistics Canada, 2021).

Rank (2019)	Country, city	Airport
International		
1	United States, Atlanta	Hartsfield-Jackson Atlanta International Airport
2	China, Beijing	Beijing Capital International Airport
3	United States, Los Angeles	Los Angeles International Airport
4	United Arab Emirates, Dubai	Dubai International Airport
5	Japan, Tokyo	Tokyo International (Haneda) Airport
6	United States, Chicago	O'Hare International Airport
7	United Kingdom, London	Heathrow Airport
8	China, Shanghai	Pudong International Airport
9	France, Paris	Aéroport de Paris-Charles de Gaulle / Orly
10	United States, Dallas	Dallas/Ft Worth International Airport
11	China, Guangzhou	Guangzhou Bai Yun International Airport
12	Netherlands, Amsterdam	Amsterdam Airport Schiphol
13	Hong Kong SAR	Hong Kong International Airport
14	Korea, Republic of, Incheon	Incheon International Airport
15	Germany, Frankfurt	Flughafen Frankfurt/Main
16	United States, Danver	Denver International Airport
17	India, New Delhi	Indira Gandhi International Airport
18	Singapore	Singapore Changi Airport
19	Thailand, Bangkok	Suvarnabhumi International Airport
20	United States, New York	John F. Kennedy International Airport
21	Malaysia, Kuala Lumpur	KL International Airport
22	Spain, Madrid	Aeropuerto de Adolfo Suarez Madrid-Barajas
23	United States, San Francisco	San Francisco International Airport
24	China, Chengdu	Chengdu Shuangliu International Airport
25	Indonesia, Jakarta	Soekarno-Hatta International Airport
26	China, Shenzhen	Shenzhen Baoan International Airport
27	Spain, Barcelona	Aeropuerto de Barcelona-El Prat
28	Turkey, Istanbul	Istanbul International Airport
29	United States, Seattle	Seattle-Tacoma International Airport
30	United States, Las Vegas	Harry Reid International Airport
33	Mexico, Mexico City	Aeropuerto Internacional de la Ciudad de Mexico "Lic Benito Juarez"
34	United States, Charlotte	Charlotte Douglas International Airport
35	Russian Federation, Moscow	Sheremetyevo International Airport
Canada		
1	Canada, Toronto	Toronto/Lester B Pearson International, Ontario
2	Canada, Vancouver	Vancouver International, British Columbia
3	Canada, Montréal	Montréal/Pierre Elliott Trudeau International, Quebec
4	Canada, Calgary	Calgary International, Alberta
5	Canada, Edmonton	Edmonton International, Alberta
6	Canada, Ottawa	Ottawa/Macdonald-Cartier International, Ontario
7	Canada, Winnipeg	Winnipeg/James Armstrong Richardson International, Manitoba
8	Canada, Halifax	Halifax/Robert L Stanfield International, Nova Scotia
9	Canada, Victoria	Victoria International, British Columbia
10	Canada, Québec	Québec/Jean Lesage International, Québec

that both in the field and in research, measures and recommendations are being deployed to support the experience of passengers living with disabilities. Results are presented to highlight relevant facilitators and barriers at each step of the journey. Also, additional aspects affecting travel experiences are presented.

3.3 Travel steps and activities

PwD travel primarily for leisure, for pleasure (34, 35). For many, travel is an enriching experience, contributing to self-fulfillment and quality of life (34). Like other means of transport, air travel can also be instrumental in maintaining social, family or friendship ties (34, 36). The desire to support travel opportunities for PwD is not a new topic in airport industry environments. To assess the impact of practices for the travel experience of passengers with disabilities, it is important to consider the complexity and scope of travel. Each stage of the journey represents a distinct experience, reality and challenge. To have a more comprehensive understanding of the results of this scoping review, they will be presented according to the different stages and activities that are required for travel.

TABLE 3 Categories, themes and codes used in the thematic content analysis.

Categories	Themes	Codes
Microsystem	Airport physical environment	Interior installations
		Exterior installations
		Vehicles (inside)
		Key step areas
	Airport social environment	Personal assistant
		Human assistance (airport)
		Other passengers
		Children and families
	Airport services infrastructures	Personal care facilities
		Stores
		Specialized rooms and spaces
		Restaurants
		Emergency resources
	Personal equipment	Luggage
		Medical devices and supplies
		Baby and children equipment
		Assistive technology, communication and information
	Personal factors	Health
		Disability
		Knowledge
Mesosystem	Organizational culture	Accessibility committee
		Values and beliefs
		Perceived utility
	Staff management	Communication
		Skills and expertise
		Training
	Internal operations	Airport regulations
		Objectives and quality standards
		Advice given to passengers
	Services management	Human assistance management
		Key travel steps services
		Customer service
		Transportation programs
		Other services and programs
Macrosystem	External partners	External partners
	Practice guidelines	Practice guidelines
	Laws and regulations	Laws and regulations
	Social disability perspective	Social disability perspective
Needs	Meaning	Leisure and pleasure
		Access to health services
		Maintaining social relations
	Autonomy	Pursuing interests and values
		Advocate
		Equity
		Independence
	Competency	Communicate
		Efficiency and time
		Flexibility
		Planning and anticipation
	Safety	Health (physical, mental and emotional)
		Emergency
		Dignity

3.3.1 Accessing the information needed to plan the journey

For PwD, planning is required to make the journey possible, especially to anticipate longer steps and potential unforeseen circumstances that could make the trip impossible (37). This is all the more important for PwD, who may need more time and accommodation (37, 38). Airplane passenger have expressed the need to feel safe in an airport and during flight, both during the normal process and during emergencies (34, 39, 40). Health is also a central concern. It is therefore essential for PwD to have easy access to guidelines for planning, anticipating and managing their health while travelling (38).

Airport and airlines websites are the primary information channels for passengers. The vast majority of airport websites offer a description of their accessible services. Where relevant, airports refer to airlines websites or contact information for travel steps where they are responsible for accessibility.

Several airports, such as Dubai and Hong Kong airports, apply recognized web accessibility guidelines for their website (41, 42). Regulations and guides are available to guide website design. European airports adhere to the European Union Council's resolution on the accessibility of public websites and their content (43). They must also comply with the law on information society services and e-commerce. Notably, Aena (operator of Spanish airports), is aiming for a Double-A validation certificate for website accessibility, as recommended by the Web Accessibility Initiative (WAI) of the World Wide Web Consortium (W3C). Similarly, in the United States and Canada, public organizations are obliged to make the content of their web pages accessible (44, 45). They must ensure equitable access to information, in accordance with the principles of Web Content Accessibility Guideline 2.0 (46). This guide presents practical ways of creating accessible web content for PwD and aims to ensure that online information respects key usability principles. More specifically, information must be perceivable, usable, understandable and compatible with assistive technology tools (38). In this sense, the sites allow the use of screen readers and offer a wide range of customization options: alternative text for image content, adjustable font sizes, modification of contrasts, accent modes on text zones, etc. At Heathrow airport, UK, AbilityNet, a group of web accessibility experts founded by the Foundation for Communication for the Disabled and the Computability Centre, was consulted on the development of the website (47).

However, website accessibility is heterogeneous. Guidelines and regulations are not always followed, and in some cases, PwD may have to ask another person to use the website or contact customer service directly. In that case, it is not uncommon for people to have to pay more for their trip (48). Additionally, finding accurate information about accessibility is usually difficult and time-consuming (49).

Some Airports, such as Toronto's Pearson Airport provide additional accessible information material, to help with planning, through the "MagnusCard" mobile application. Notably, this information enables people with autism to plan the trip with greater ease and reduce the stress of the unfamiliar (13). Cerdan Chiscano (50) also recommend using dedicated material to help people with autism prepare the trip.

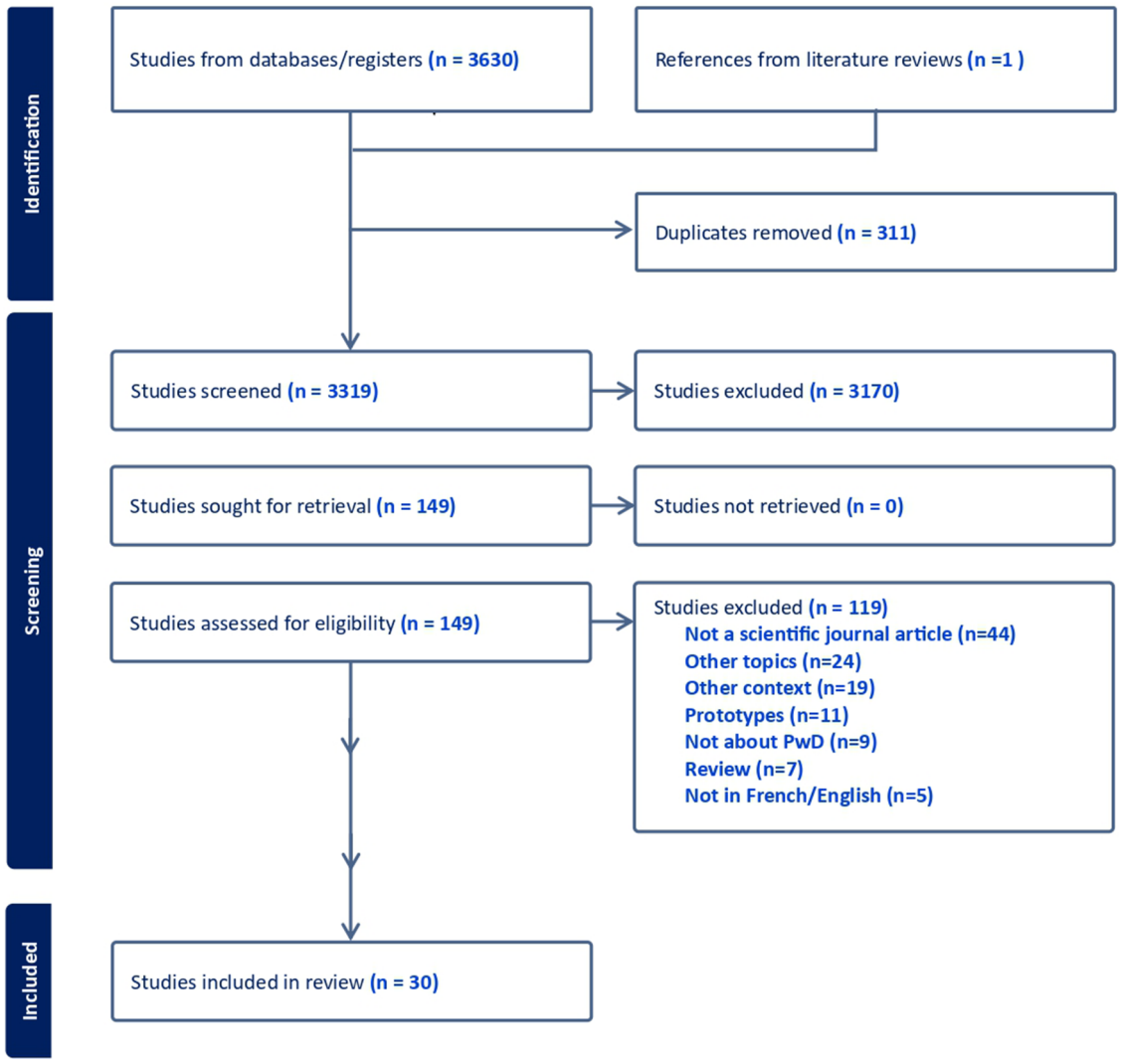

FIGURE 1
Scientific literature selection process: PRISMA diagram. Licensed under CC BY 4.0, Page et al. (33).

3.3.2 Getting to and from the airport

Accessibility to and from airports largely depends on the accessibility of the means of private or public transport used. At airports such as Calgary, Dallas and Singapore, some public buses are equipped to accommodate wheelchair users (36, 51, 52). In Singapore, a tactile guidance system, real-time interactive maps and audio announcements are used to guide PwD in the subway (51). In some cases, such as Dallas-Ft Worth or Heathrow, shuttles between terminals are fully accessible to wheelchair users and passengers with reduced mobility (52, 53). Other partner organizations sometime offer accessible transportation options, as in Denver's airport, where wheelchair-accessible vans and hand-operated cars are available for rental (54). On another note, to facilitate arrival at the airport, PwD may have access to dedicated parking spaces and fee exemption, such as in Incheon Airport, Republic of Korea (55).

However, few airports provide clear information on the proportion of services accessible, or their degree of availability. Cole et al. (49) highlight that there is a limited number of accessible vehicles and transportations. This can be problematic considering that in many cases, people are required to use several means of transport. For instance, passengers at Los Angeles Airport often need to do additional transit between remote terminals (56). Additionally, while most airports offer dedicated outdoor accessible points, high passenger traffic can reduce the efficiency of accessible transports (57). Finally, many airports insist that PwD arrive at the airport at least three hours in advance. While this recommendation applies to all passengers, in the case of PwD it may affect access to the services they require (53).

3.3.3 Obtaining human assistance

Human assistance services are offered at all the international airports included in the analysis. Human assistant services are mainly designed to compensate for the lack of accessibility of the physical environment. They aim to support the mobility,

TABLE 4 Included studies characteristics.

Study characteristics		Number of studies
Origin of the study	Europe	15
	North America	11
	Asia	5
Year of publication	2009	2
	2010	4
	2011	1
	2012	2
	2014	2
	2015	1
	2016	1
	2017	1
	2018	2
	2019	3
	2020	5
	2121	4
	2022	3
Aim of the study	Highlight accessibility issues	16
	Evaluate accessibility and propose solutions	11
	Address accessibility issues	4
Studied population	PwD	22
	Older adults	4
	Employees	4
	Accompanying person	1

communication and access to information for passengers with disabilities, through the different travel stages, as in Madrid Airport (58). Services are usually free, but some airlines may charge for assistance services or for enhanced services (59). In most cases, the assistants wear easily recognizable colour-coded jackets, so that they can be quickly identified by passengers. They are usually present in dedicated kiosks, close to the entrances and hotspots of airports. For example, at Indira Ghandi International Airport at Delhi, India, assistants trained to intervene with PwD are available at accessible check-in or information desks (60) and in Dallas, USA, staff are present directly in the terminals, 24 h a day, every day (52). Assistance can usually begin at any of the airport's access points. In Incheon, for example, pick-up can start as soon as you arrive at the subway station (55). When passengers are accompanied by an assistant, services often involve the use of a wheelchair, in addition to the attendant, regardless of disability (61).

PwD have to plan in advance for dedicated human assistance services, to minimize waiting times at the airport. In most airports, the airport, airlines and other contractors share the responsibility of providing assistance (62). Responsibilities vary between airports. In Calgary, for example, the airlines take charge of the passenger from check-in to boarding (36), whereas at O'Hare International Airport, the airlines coordinate services from the boarding gate (63). Early notice from passengers is often cited as a facilitator in the organization and speed of services offered. At Madrid international airport in Spain, for example, passengers requiring an attendant must contact the airline, to obtain a pass for the attendant (58). PwD can contact the airport using a request form, using a mobile application or directly on site at dedicated kiosks (36, 58). However, waiting times vary widely, depending on the number of passengers and the contact method. At Schiphol airport, Amsterdam, for example, a person arriving on site to request assistance, without having made a reservation, may have to wait up to 45 min. This waiting time does not exceed 30 min when the person has booked an assistant at least 48 h in advance (64).

To facilitate punctual assistance to people with invisible disabilities, 140 airports around the world are also partners in the "Hidden Disabilities Sunflower" program, such as Denver Airport. This program offers people with invisible disabilities the opportunity to wear a sunflower symbol, making it "visible" to those around them that they may need extra help. Some airports additionally train employees on certain invisible conditions or disabilities (61). At KL International, Malaysia, "The Butterfly Effect" service offers integrated assistance to people with invisible disabilities, particularly those with autism. People using the program receive additional documentation, are welcomed and guided around the airport's accessible infrastructure (65).

For airport, human assistant fleets requires intensive management. Competence and training are directly linked to service quality (66, 67). Wang and Cole (68) highlight the importance of basic health knowledge training for employees. Employees should be prepared to compose with the common situations PwD may encounter during travel. Additionally, the desire to help, patience, the ability to offer clear information, to relate and to support comfort are key determinants of service quality. At Schiphol in Amsterdam, Netherlands, assistants are given specialized training in safety, risk management and intervention (64). In Dubai, employees are trained according to Air Carrier Act's standards and a certification program is in place to ensure an adequate level of competence among employees that may interact with PwD (69).

Human assistance services present several considerable challenges for airports organizations. First, assistants have to contend with low wages, irregular schedules, and physically demanding conditions (62, 70). These conditions result in particularly high staff turnover. For instance, over 60% of assistants at Pittsburgh International have been with the company for less than 2 years. This situation affects service quality and adds stress to the remaining assistants (62).

Also, McCarthy (67) and Cole et al. (49) point to a significant gap in the training received by employees. Indeed, it is not uncommon for employees from different departments or management to receive different training, in terms of quality and comprehensiveness. In this study, participants employed in airports mentioned that they would like to see experts offer systematic, standardized content on services and inclusion for passengers with disabilities. They would also like training on certain types of disability, communication and transfers. Gaps in employee training can create a low sense of competence, which can negatively affect the relationship with the person being supported (67). Passengers' experience corroborates this gap. For example, parents of children with disabilities are often reluctant to have them handled by assistants due to a lack of experience (35). This challenge is all the more pressing in airport contexts,

TABLE 5 International airport's physical environment aspects used to improve mobility.

Physical environment features	Current practices in airports	Scientific literature recommendations
Signage	Large fonts Contrasting colours (e.g, Heathrow) Simple langage Anti-reflective coating (e.g, Paris)	Abundant use of clear and simple signs (40, 50). Contrasting colours Large fonts Static and dynamic signs Intelligent signs with multiple sensory modes Visual signals at boarding gates (71). Use of static, dynamic and intelligent signs (57)
	High luminosity day and night (e.g, Toronto)	Lighting should be provided for all times of the day and night (71)
Outdoor		
Meeting points	Placed near the entrance (e.g, Madrid)	
Parking	Accessible, reserved, and close to entrance parking spaces (e.g, Atlanta)	Van-accessible spaces (49)
Curb	Accessible drop-off areas (e.g, Québec)	
Indoor		
Entrance door	Large entrance, Sliding doors (e.g, Winnipeg) Carpeted vestibule to reduce residue, White cane bars (e.g, Calgary)	No steps (49)
Flooring	Hard materials Non-slippery materials Textured paths and lanes (e.g, Beijing airport)	Hard materials (71) Non-slip material Light-coloured Textured path Braille blocks Use of LED paths, colour coding, tactile information and luminescent materials (57)
Ramps		Whenever possible to limit required efforts for PwD and assistants (70) Limited steepness (49)
Handrails	In main circulation areas, to support mobility and orientation (e.g, Beijing)	
Seating	Reserved seating, placed throughout terminals for respite and waiting areas (e.g, Beijing Airport) Raised for people who have trouble getting up (e.g, Paris CDG)	Regular intervals to reduce walking distance (71)
Meeting points and landmarks	Located near recognizable features, highly signposted, often used for kiosks and assistance counters (e.g, Madrid)	Should be placed to minimize walking distances (71)
Elevators	Braille buttons Voice assistance (e.g, Canton) Mirrors Tactile signs for directional information Strategically placed near staircases and escalators (e.g, Calgary)	Should be placed to minimize walking distances (71)
Escalators and stairs	Placed in high traffic areas (e.g, Denver)	Should be large: Limited space of escalators can cause issues for large mobility aids and during emergencies (39) Tactile signs at both ends should be present to indicate the direction of movement for people with visual impairments (61). Should be placed to minimize walking distances (71)
Vehicles	Wheelchairs rent or free self-service (e.g, Singapore) Electric vehicles Buggies Carts (e.g, Dubai)	
Restroom	Dedicated cubicles in toilets (one or two per general public room) (e.g, Québec) Gender-neutral toilets for personal attendants Increased space for wheelchair circulation Handrails Lowered sink Objects table Coat Hook Lowered hand dryers Lowered water fountain (e.g, Beijing Airport)	Large spaces for wheelchair circulation. Grab bars. Clean spaces for medical procedures (49)

where employees require extensive knowledge and skills, such as the ability to speak several languages (61).

In addition, coordination and communication between assistants is hindered by factors such as distance, complex environments, numerous requests for assistance and dependence on walkie-talkies, leading to gaps in real-time information, errors and a decline in service quality (62). Also, hierarchical tensions within the organization, negative perceptions of colleagues and negative interactions with passengers can reduce service quality (67).

Finally, the employee fleets of airports and airlines are under different management. Management processes should include efficient channels of communication between different parties, to improve the fluidity, efficiency and quality of services, particularly during service transitions (68).

3.3.4 Getting around the airport

Most airports have physical installations designed to facilitate the mobility of PwD. The different type of mobility amenities in the physical environment is presented in Table 5.

In all the airports surveyed, regulatory exemptions are in place to allow the free circulation of people with assistance dogs. However, it is the passenger's responsibility to inform the airlines and provide the necessary documentation (animal passport and identification documents) to justify the need for a service dog. Many airports, such as Calgary and Dallas's airports, offers pet-friendly outdoor areas, before and after security. However, in numerous cases, those relief areas are too scarce (49).

Despite those features, several challenges are faced by PwD when they navigate airport environment. Firstly, wheelchair users have to check in their wheelchair for transportation (72). For this reason, many airports offer self-service wheelchairs for both indoor and outdoor use, they may not be comfortable and affect individual autonomy (66). In addition, wheelchairs may be damaged during transit. Beside the inconvenience of not having a wheelchair due to damage, insurance procedures in those cases are complicated (49). Also, it is not uncommon to have to change wheelchairs twice: from their personal wheelchair to a wheelchair for use in the airport, and then to a smaller wheelchair for boarding the plane.

Furthermore, passengers have to change vehicles between the different stages of the journey. Besides, access to vehicles varies greatly between airports. However, the vast majority have at least electric vehicles in the terminal waiting areas after security screening.

3.3.5 Information and wayfinding at the airport

Several practices and technologies are in place in airports to allow PwD to access to timely information. Hearing loops, such as those used in Tokyo Haneda Airport (73), enable people with hearing disabilities to obtain crucial information about flights and airport situation. Hearing Loops are assistive listening systems, designed for people wearing hearing aids (T-coil, cochlear implants and streamers), that improve the clarity of information and communication. Also, a number of teletypewriter telephones (typed messages telephone) and video relay services are in place in many airports to facilitate communication between passengers and stakeholders.

Also, airports usually rely on the use of flight information panels, coupled with auditory information on changing situations (cancellation, etc.). Information panels should present data multimodally, without separating situational and contextual information (74). Park et al. (38) point out that most airports aspire to transmit all information to PwD in a lossless, time-efficient and intuitive way (38). However, it can be difficult for PwD to obtain real-time flight information. For example, if important changes occur and are announced audibly, a hearing-impaired person may not have the initiative to reconsult the information board (61, 74).

Interestingly, for some PwD, other passengers can act as a supportive information resource. While these interactions are positive most of the time, discriminatory or marginalizing attitudes or remarks may be made (49, 61).

In addition, Toronto Pearson Airport recommends that people with visual impairments use the Aira application, which enables them to communicate with an assistant via videoconferencing, in real time (75). Another application, based on the use of IBeacon in airports, offers real-time information at every step, to enable route decisions to be made, based on time and distance. The information presented is multimodal (haptic feedback, audio, text) and flexible (e.g, customizable level of detail) (74). However, for indoor navigation systems, vast airport spaces can make it difficult to install beacons covering all possible paths. Indoor systems are also less accurate than outdoor systems, which can be a problem when lanes are narrow or when hazardous installations are nearby (61).

3.3.6 Check in

Several airports, such as Singapore Changi or London Heathrow offers dedicated accessible counters in check-in areas (51, 53). In some airports (e.g, Amsterdam Schiphol, Dubai International) and airlines (e.g, Delta Airline or Qatar Airways) offer priority check-in for people with disability (64, 69). This service allows PwD to avoid long waiting times and complete the check-in with assistance. At all airports, airline or airport employees are present at check-in counters and in queues to offer assistance. Airports increasingly use automatic accessible kiosks and touchscreen, to improve check in efficiency. At Hong Kong international, those devices are adjustable in height and can display larger fonts and contrasts for PwD (76).

Check-in, however, can be challenging for PwD. At every key travel stages, airports are particularly dense in terms of people and traffic. The density of people can hinder access to counters and reserved spaces for PwD (57).

3.3.7 Security screening

The high passenger traffic, the impossibility of using regular scanners, the additional equipment to be checked and the sometimes confined spaces are additional stressors for PwD during security screening (49, 77, 78). To bridge this gap, priority screening and dedicated lanes can be in place, such as Hartsfield-Jackson Atlanta International Airport (79), to avoid traffic and high-waiting times. Furthermore, as in Frankfurt Airport, Germany, PwD can register 72 h prior to the journey to book for a specific time to pass security screening. Also, passengers for whom the usual security procedure may not be possible due to their disability can contact security services for information or to request modified procedures compatible with their conditions, medical devices, service animal, technical aids, etc (72). Furthermore, while security agents usually receive training to assist people with disabilities (78), they cannot provide wheelchair mobility assistance through the security

process (72). However, in most airports, PwD can obtain human assistance either from airlines or personal attendants to help with security steps. In Denver Airport, for instance, a pass for non-travelling companions enables PwD to obtain assistance with security and onward areas (54).

Usually, airports' internal regulations anticipate the additional equipment that PwD will have to carry during screening. For instance, The Canadian Air Transport Security Authority offers extensive information of regulations, exemptions and facilitators for the transportation of medical and other essential items for PwD (80). In Singapore, technical aids are checked separately and an alternative line to metal detectors, with a manual check, is provided for wheelchair users (51).

PwD still face several challenges when going through security screening process. Indeed, they often have to carry out additional documents, as in Kuala Lumpur airport in Malaysia, where passengers are required to keep their medical and identity documents with them at all times (81). Also, the process is also generally more anxiety-provoking and time-consuming, due to the need for a manual search of aids and personal belongings (78). The strain of having to part with one's technical aids and medical devices can be a stress vector for passengers, who fear that their belongings may be lost or damaged in the process (61).

3.3.8 Use facilities and wait at gates

Few airports provide detailed information on assistance to PwD when they are waiting in the gate area. Yet, the ability to use restaurants, bars and other facilities in this area is a key factor in airport accessibility (71). One of the problems at this stage is the transfer and change of responsibility of organizations in human assistance. This pose obvious issues, when people have to use facilities for essential needs, such as having to use the toilet (61). In some Airports, such as Dubai International, a number of accessible facilities are available after security screening, as long as the individual is able to move around the area. Sometimes, other activities in the airport can be supported by assistance services (69). At Heathrow, for example, an attendant can be deployed to help people shopping in the facilities (53).

3.3.9 Boarding and disembarking

In every airport surveyed, airlines are responsible for providing assistance with boarding and disembarking. Individuals must inform companies prior to the journey or during check-in, for any specific required accommodations. In the majority of cases, people board and disembark the aircraft at a dedicated time, before or after other passengers, to ensure they have more time and assistance to reach their seat or get out of the plane, as explained at Paris Charles de Gaulle Airport (82).

Spaces in airplanes almost never accommodate wheelchairs (Holloway et al., 2015). Small type of aisle chairs are used to enable wheelchair users to reach their seat, exit or restrooms (70, 83). However, several people with obesity report negative experience with the inadequacy of airports and airplanes' chairs (37).

Boarding and disembarking may have to take into account the different possible ways planes dock airports. Most boarding relies on the use of jet bridges, which are movable closed bridges connecting terminals and airports. However, they are not used in every situation, for example, when boarding and disembarking take place directly onto the airfield ground (tarmac). Information on procedures in that case is not available on airport websites. Some airports, such as Toronto Pearson or Kuala Lumpur International, recommend that passengers directly contact airlines for assistance and information with specific boarding and disembarking procedures (10, 84).

3.3.10 Customs and immigration

Few airport websites offer information on accessibility and inclusion at customs and immigration. At Dubai International, *a priori*ty lane with a dedicated counter and a person trained to assist PwD facilitates the declaration process. The scarcity of information on airport websites is not surprising, since those services are managed by immigration and customs agencies. For instance, the Canadian Border Services Agency offers information on priority and alternative lines: they can provide assistance in completing the declaration and documents, accommodate sign language and handle personal items for more extensive clearance (85)

To support independence, it is recommended that PwD be offered the opportunity to use accessible automatic information and service terminals (e.g, customs service terminal) (57, 86). The IATA offers a practical guide to support the implementation and use of automatic border control systems (86). However, those types of technologies can be hard to implement in airports, if they are perceived to be too costly to implement, or if too few people are likely to use them (86).

3.3.11 Managing luggage and personal belongings

Managing luggage during the journey can be a difficult task for people with disability, whom mobility is reduced (37, 49). In addition, they often have to travel with additional equipment, required either for their health or their activities (apnea monitors, personal supplemental oxygen, mobility aids, etc.), that can affect travel in many ways. First, such items take up space that might already be limited (35). Also, people travelling with wheelchairs or other bulky equipment need to plan for their handling. Inconsistencies and not knowing what happens with equipment handled by airport's employees can be stressful for PwD (66).

Luggage assistance is included with human assistance services at most airports. For instance, at Calgary Airport, help is offered as soon as the person arrives at the airport to check in, and when collecting from conveyors after their flight (36).

However, those services need to be planned prior to travel, and might require waiting time at arrival, depending on the destination. Also, this step can be challenging for PwD, when they are alone or when services are unavailable. Finding and lifting bags from conveyors may not always be possible. In some cases, PwD may try to avoid having a checked baggage, to avoid this step altogether (61).

3.3.12 Sustaining travel experience

PwD often express the need to be able to move around airports independently, without depending on constant assistance (61, 86). They need to have access to the same opportunities and channels as other passengers. For them, airports should pay particular attention to the risk of perpetuating the normative transport culture, which allows passengers without disabilities more efficient mobility from the outset (48, 86). However, the way services currently operate can create a sense of marginalization—even humiliation—among PwD (49). For instance, people with visual impairments may feel that their autonomy is being taken away, when assistants present them with a wheelchair (61). Another example is the assumption that people in wheelchairs are unintelligent and dependent (49). Passengers wish that employees would be trained, and use communication strategies that promote their autonomy (67). Also, the use of waiting areas isolated from other passengers can create a sense of exclusion and prevent PwD from exploring and using the various infrastructure offered by airports (86). The way PwD are perceived and conceptualized in airports has also a direct impact on the way they are treated (37, 61, 67). PwD are referred to by many names: special passengers, people with reduced mobility, the disabled, handicapped, challenged passengers, passengers with special needs, People of Determination, people with impairments, old, weak, sick. Budd and Ison (87) recommend standardizing the definition of PwD or persons with reduced mobility, to increase the quality and consistency of services.

Regulations, as well, play a decisive role in improving travel accessibility and experience (61). International organizations such as the International Civil Aviation Organization (ICAO) and the International Air Transport Association (IATA) have taken a stand on the need to accommodate PwD. They emphasize equity in service provision and accessible approaches, particularly at borders (86). In the United States, the Air Carrier Access Act (ACAA) and the Americans with Disabilities Act (ADA) protects people with disabilities from discrimination at all stages of travel (67, 74). Similarly, in Canada, regulations on transport accessibility for PwD are at the heart of strategic planning for international airports, as in Toronto and Calgary (88, 89). In Europe, regulations for the equity and quality of services for PwD, such as the Convention for the Rights of PwD, guarantee free assistance, at all stages of travel (61, 70). Nonetheless, respect and adherence to laws and regulations can be a challenge for PwD. In some cases, laws exist but are little known. For instance, the Department of Transportation regulation guarantee that PwD are subject to the same travel fees, regardless of how they communicate with services. However, Lazar et al. (48) have shown that in many cases, airline agents on the phone do not comply with this obligation, even when it is explained to them. To prevent inconsistencies in laws application and inequities, Budd and Ison (87) recommend that airport companies inform passengers on laws and their responsibilities for travel. They should also participate in the review of laws, and their critics, to prevent abuse of service, and clarify ambiguous regulations.

Every airport puts forward a customer service department, to sustain travel experience. For example, Toronto airport has set up a 24-hour helpline, live chat and contacts phone number. At Tokyo Haneda airport, dedicated customer service agents are deployed at accessible counters (73). Nevertheless, the contact process can sometimes be difficult. The lack of accessibility of some websites can deter PwD from getting in touch with customer service to raise issues (48).

4 Discussion

This scoping review highlights many practices and challenges for accessibility and inclusion in airports. At first glance, the challenges and negative experiences of passengers with disabilities may appear paradoxical, considering the large number of measures in place to support their travel experience. However, current practices may underestimate the complexity of air travel (90). Conceptions of accessibility and inclusion can be influenced by visions that may be mistakenly believed to be universal (e.g, Western view of disability). Indeed, air travel has many meanings and purposes and can be pursued in many different ways. This reality is particularly important in airports, which welcome people from all over the world, with very different cultural backgrounds. Some salient challenges experienced by PwD can be deduced from this exploration. On the one hand, they carry a heavy burden when travelling, and experience tensions with airports' views of their identity. On the other hand, the scale and complexity of airports are a major challenge for stakeholders in supporting PwD.

4.1 The burden of travel for PwD

The results show that, while many services exist, passengers who need assistance have to plan their journey to a much greater extent. Indeed, services are not always immediately available to PwD, without reservation. If they are, they often require additional time for deployment. Implicitly, this approach to services, places a great deal of responsibility on PwD in their ability to travel. This vision of accessibility is rooted in current practices. Indeed, travel guides designed for PwD place considerable emphasis on passengers' and families' responsibility for travel. Several additional steps are required, and it's up to PwD to prevent setbacks at each step. Many organizations are explicit on this topic: they specify that the individual is responsible, and sometimes decline responsibility for the failure of the trip, if arrangements have not been made by the passenger beforehand. This position is at odds with the recommendations or obligations issued by several governments. Indeed, the legal framework suggests an inclusive approach, where PwD have the same opportunities as any other passenger. In a context where this additional burden can be detrimental to the possibility of making the journey, it is legitimate to think that PwD may effectively not have the same opportunities as other passengers.

Planning is often at the forefront, in a context where the notion of time is critical to air travel. The success of the journey depends in particular on the person's capacity to get through the various stages

in a timely manner. The deployment and use of alternative services or channels can lead to additional delays in the journey. Airports are well aware of this, as many insist on the importance of arriving at the airport well in advance. Long waits for an assistant is one example that raises concerns about the management of travel time. The chain of steps involved in air travel is long and complex. The accumulation of additional delays at each stage is a major concern for passengers with disabilities.

These issues are exacerbated by the ambiguity surrounding information on accessibility. The use of generic rather than descriptive adjectives and terms, such as "accessible" without further detail, is common practice on websites. Since people's needs are as unique as they are diverse, each individual is in the best position to assess their own needs. This can hinder PwD's preparation, as they cannot always conclude whether the services in place are sufficient to meet their specific needs. Similarly, few really prepare PwD for the challenges they will face at airports. Most airport organizations present the services they offer, to demonstrate that the journey will be accessible, without acknowledging limitations. Heathrow Airport in London, UK stands out in this respect. The organization conveys information about accessibility, acknowledging the challenges that will accompany the journey (e.g, additional delays, regulatory limitations, etc.) (53).

For the same reason, in addition to increased preparation, passengers with disabilities need to have a higher level of knowledge of air travel (5, 91). The inability of people to anticipate problematic situations that may arise at various stages jeopardizes their ability to travel.

4.2 The tension of the PwD vision

One of the main reasons why PwD don't travel is the dehumanizing nature of travel, as described by Darcy (5). The current state of services and their description corroborate this experience. The medical vision, focused on the disability rather than the person, is predominant, both in airports and among external actors involved in services. PwD are categorized in two ways, either by their disability, or by the needs deduced from their disabilities. This disability-centric perspective influences services in several ways.

Firstly, the complexity and uniqueness of PwD are often overlooked. By reducing people to their disability or perceived needs, services are neither personalized nor respectful of passengers' agency. Rarely can people decide or express what they want in terms of the level of assistance, the route he wishes to take or the places he wishes to visit. Moreover, although passengers' vision of autonomy varies widely, it is often conceived in just one way, at airports. For example, employees' level of knowledge about disability can lead to the development of a perception that PwD need to be assisted in everything they do (67). On the other hand, services and infrastructures have a well-defined objective: to complete travel stages. To do so, it is assumed that people need to meet their primary needs, and to mobilize. If these needs are important to the journey, it's possible that other needs are just as important. It is rarely possible for passengers with disabilities to take full advantage of the wide range of activities that airports have to offer. In particular, human assistance services are often well-defined to a specific route, which only allows the completion of travel stages. Also, the approaches are often the same, regardless of the passenger. The unique meaning of travel for the individual is therefore rarely called upon.

Secondly, services are focused on inability, rather than strengths. In many cases, the passenger must inform the organization in advance about the things he or she cannot do (5, 6). Implicitly, many ask PwD to carry out a prior analysis of their functioning, for the different stages of the journey. In addition to the in-depth knowledge of the journey that this requires of the passenger, this upstream perspective encourages the use of compensatory means, which can exacerbate passengers' feelings of marginalization. Indeed, such approaches are based on the presumption that the individual is at the root of the problem, rather than on the recognition of a possible mismatch between the individual's context and the occupation. As a result, PwD may feel a heightened sense of guilt in the face of travel difficulties.

Also, the vision and practices of accessibility in the airport context can be stigmatizing for PwD. On the one hand, the terms used to designate PwD often have an unfavourable connotation in relation to the person's abilities. The use of terms such as "weak, challenged, sick" is indicative of the objectives pursued by services and infrastructures. Consequently, employees interact with these people from that perspective, creating, unwillingly, a dehumanizing and stigmatizing experience (61). On the other hand, categorizing people's needs leads to the use of disability-related labels. Many PwD do not identify themselves as "people with reduced mobility," even though this is the term most often used at airports around the world. In addition to not accurately representing PwD, this term can lead people to believe that PwD only have mobility needs. In fact, a very significant proportion of airport services are designed to support PwD mobility. Services developed to meet other needs are rarer.

Cole et al. (49) warn the industry that meeting the minimum requirement of the law is not enough. Better awareness and education on PwD are required to tackle the stigma and devise more inclusive approaches. Critical thinking about PwD is required to avoid insensitive or discriminatory practices (49).

Increasingly, airport organizations are expressing a desire to change and redefine this vision. Toronto Airport, for example, explicitly makes this distinction in its position statement on accessibility: "We recognize that passengers and employees don't need to adapt to have their needs met; we do" (92). Passengers living with disabilities insist on the importance of bringing this critical reflection to the development and planning of accessibility practices (5).

4.3 Organizational challenges at airports

The magnitude and complexity of airports are a major challenge for the organization of services and infrastructure. Many stakeholders are required to ensure the international reach of airports. Numerous airlines, airport operators and third-party

companies have to work together to make travel possible. Each of these organizations has to deal with different realities, objectives and sometimes regulatory frameworks. This reality of shared responsibility can hinder service synergy. The many different organizations working on accessibility have mandates defined for specific actions or areas (93). As mentioned before, for example, airport organizations are responsible for getting people to the gates, while airlines are responsible for boarding and disembarking. Elsewhere, as in Calgary, some airlines take charge of PwD as soon as they check in. The need to deal with heterogeneous operating modes can hamper continuity of service (93). Also, there is little evidence of sustained communication between these stakeholders: usually, it's the passenger who has to do the bridging (61). This complexity is exacerbated by the many stages of travel, for which PwD need support. Because of the way stakeholders interact, the PwD travel process is fragile. It only takes a perturbation at one stage of the journey to jeopardize the entire planning and organization of the other stages. Safeguards are not always in place to compensate for the uncertainties of the journey, and service providers do not always assume responsibility for making the journey possible at all costs. Moreover, this state of communication is conducive to service errors. Certain needs may be misinterpreted or poorly conveyed, resulting in a reduction in service quality (5, 61). Also, transitions between different services are often criticized in the passenger experience. The lack of a bridge between the transfer of responsibility is at the root of major discomfort situations for passengers. For example, they may have to wait for long periods, with no assistance available for their basic needs. In addition, airports are home to a complex network of human resources. Assisting PwD requires specific knowledge and skills. Maintaining these skills is a challenge at many airports, which have to cope with high staff turnover, limited resources (49) and poor access to skilled labor. These training and skills issues can also diminish the benefits of initiatives designed to promote inclusion. For example, programs aimed at increasing the visibility of people with invisible disabilities can be compromised if assistants have little knowledge of the approaches to be favoured.

More and more airport organizations are talking about inclusion. In many countries, legislation is pushing organizations to think critically about equal opportunities for PwD. Airports often wish not only to meet their legal obligations, but also to develop the quality of their services and travel experience. Major challenges remain in respecting passenger rights (48), and more generally in service quality. However, the various initiatives, calls for projects and partnerships set up by airports demonstrate their interest in narrowing this gap.

4.4 Strengths and limitations of the study

This study has several strengths. Firstly, the methodological choices, informed by the scope review method, contribute to the study's relevance and credibility. The process of identifying and selecting articles was carried out by two people, double-blind. Disagreements were discussed ensuring accuracy and comprehensiveness. Secondly, systematic consultation of the websites of airport organizations greatly contributed to data richness and comprehensiveness. Airport organizations are the main resources for obtaining information on accessibility services and infrastructures. Their inclusion was essential to obtain an accurate picture of the state of accessibility and inclusion in international airports. Moreover, the varied origins of the airports also enabled us to highlight critical differences between the various international airports. At the same time, we took a broad look at the contextual aspects that play a role in accessibility. By considering all stages of the journey, it was possible to highlight important gaps, transversal to accessibility and inclusion practices (e.g, issues of disability vision and organizational challenges).

Several limitations should also be noted. In particular, we did not systematically include Google search results when identifying documents. In the search for accessibility practices, the vast majority of results from the Google search engine refer to international airport websites. Since the Google search is conducted from Canada, the search favoured results related to North American airports. However, for the purposes of this study, we wanted to consider airports in terms of their activities, rather than their location. With this in mind, we chose to proceed systematically by directly identifying the sites of the world's busiest international airports. Also, as mentioned previously, accessibility information on websites is sometimes ambiguous and vague. Generic terms such as "accessible" are used to include a range of features and accommodations that are not described on the sites. For this reason, it was not possible to establish clear data on the frequency of arrangements and services as part of this scoping review. Such results could have raised issues of data accuracy, for airports that do not specify or whose information is too general to conclude on the presence or absence of an accessibility feature.

Furthermore, only scientific literature in English and French was considered. It is likely that accessibility or inclusion practices are presented in documents in other languages. Secondly, few data focus on the experience of passengers with disabilities. Although the aim of this study was to highlight accessibility practices, understanding the experience of passengers with disabilities is equally important in improving services. Similarly, understanding the needs and experience of individuals is crucial to taking a stance on the occupational participation of passengers with disabilities. To this end, Prajapati et al. (94) are currently conducting a scoping review on the experience of PwD when flying.

5 Conclusion

Air travel is very important for the well-being of everyone, and, of course, of PwD, but also for their fundamental right to equal opportunities. Air travel is increasingly becoming a common means of transport, sometimes essential to many important roles in people's lives. Even today, a considerable number of PwD do not travel, due to the difficulties anticipated in the process (91). For this reason, various organizations are working on several

fronts, to support access to travel for these individuals. This study has painted a picture of accessibility and inclusion in airports around the world. A wide variety of practices, at many contextual levels, were identified. The results are an important step towards understanding the main challenges affecting the occupational participation of PwD when travelling through international airports. Several possible directions for future research were raised. In particular, gaps relating to the burden of travel for PwDs, their vision by the various stakeholders and organizational management were highlighted. Narrowing these gaps is crucial, given that it's not enough for airports to be "accessible", but that they must offer PwD a satisfying and humane travel experience.

For this reason, this study is the first step in a larger project, funded by Canadian Accessibility Standards, aimed at improving inclusive accessibility in Canadian airports. We will be accompanying PwD of various profiles through the various stages of their journey, to gather their perceptions of the travel experience. The results will be used in conjunction with this study to formulate recommendations and solutions for inclusive accessibility.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

DG: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Writing – original draft, Writing – review & editing, Validation, Visualization. EM: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing – review & editing. FR: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Writing – review & editing. JR: Data curation, Validation, Writing – review & editing. AH: Conceptualization, Methodology, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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Appendix A: Scientific literature research terminology

All free terms were searched within titles and abstracts

Medline (via ebsco)

(disab* OR "special need*" OR incapacit* OR "physical disorder*" OR "reduced mobility" OR "physical* challenge*" OR (MH "Disabled Persons+") OR visual* impair* OR vision OR blind* OR "deaf*" OR hearing* OR (MH "Sensation Disorders+") OR intellectual OR "mental* deficienc*" OR "Developmental" OR "mental* ill*" OR "mental* disorder**" OR "mental* health disorder*" OR "psychiatric disorder*" OR "psychiatr* ill*" OR neurodivergen* OR neuro-divergen* OR autism OR autistic OR cognitive OR dementia OR (MH "Mental Disorders+") OR elder* OR older OR senior OR aged OR (MH "Aged+") OR (MH "Aging+") OR Obes* OR (MH "Obesity+")) **AND** (OR modif* OR "access* program*" OR "access* measure*" OR "universal access*" OR design* OR "assistive technolog*" OR "architectur* access*" OR adapt* OR Signage OR (MH "Architecture+") OR (MH "Self-Help Devices+") OR Inclusiv* OR discriminat* OR Respect* OR Equity OR Justice OR tolerance OR prejudice OR (MH "Social Inclusion") OR (MH "Social Discrimination") OR (MH "Respect") OR (MH "Prejudice") OR (MH "Social Justice") OR (MH "Social Isolation") OR Guideline* OR "Framework" OR "Frame of reference" OR "Best practice*" OR recommendation* OR polic* OR Rule* OR Regulation* OR (MH "Models, Theoretical") OR (MH "Guidelines as Topic+") OR (MH "Policy") OR (MH "Health Planning+") OR ([Neutral* OR equity OR (MH "Gender Equity")] AND [bathroom* OR restroom* OR Utilit* OR Facilit* OR (MH "Toilet Facilities")])) **AND** (Accessib* OR Orientation OR Mobil* OR (MH "Architectural Accessibility") OR (MH "Spatial Navigation") OR inclusiv* OR participation OR (MH "Social Participation") OR (MH "Community Participation") OR use OR usability OR utilization OR capab* OR capacity OR ability OR adequacy OR appropriateness OR experience) **AND** (airport* OR "air transport*" OR "airline*" OR aircraft OR (MH "Airports") OR (MH "Aviation+") OR (MH "Air Travel")

CINAHL (via ebsco)

(disab* OR "special need*" OR incapacit* OR "physical disorder*" OR "reduced mobility" OR "physical* challenge*" OR (MH "Persons with Disabilities+") OR visual* impair* OR vision OR blind* OR "deaf*" OR hearing* OR (MH "Sensation Disorders+") OR intellectual OR "mental* deficienc*" OR "Developmental" OR "mental* ill*" OR "mental* disorder**" OR "mental* health disorder*" OR "psychiatric disorder*" OR "psychiatr* ill*" OR neurodivergen* OR neuro-divergen* OR autism OR autistic OR cognitive OR dementia OR (MH "Behavioral and Mental Disorders+") OR elder* OR older OR senior OR aged OR (MH "Aged+") OR (MH "Aging+") OR Obes* OR (MH "Obesity+")) **AND** ((modif* OR "access* program*" OR "access* measure*" OR "universal access*" OR design* OR "assistive technolog*" OR "architectur* access*" OR adapt* OR Signage OR (MH "Facility Design and Construction") OR (MH "Assistive Technology Devices") OR (MH "Signage") OR Inclusiv* OR discriminat* OR Respect* OR Equity OR Justice OR tolerance OR prejudice OR (MH "Social Inclusion") OR (MH "Attitude to Disability") OR (MH "Respect") OR (MH "Prejudice") OR (MH "Social Justice") OR (MH "Occupational Justice") OR Guideline* OR Framework" OR "Frame or reference" OR "Best practice*" OR recommendation* OR polic* OR Rule* OR Regulation* OR (MH "Practice Guidelines") OR (MH "Conceptual Framework") OR (MH "Rules and Regulations") OR (MH "Government Regulations") OR (MH "Public Policy") OR ([Neutral* OR equity OR (MH "Gender Equality")] AND [bathroom* OR restroom* OR Utilit* OR Facilit* OR (MH "Toilet Facilities")]) **AND** [Accessibility OR Orientation OR Mobil* OR inclusiv* OR participation OR (MH "Social Participation") OR use OR usability OR utilization OR capab* OR capacity OR ability OR adequacy OR appropriateness OR experience] **AND** (airport* OR "air transport*" OR "airline*" OR aircraft OR (MH "Aviation") OR (MH "Aircraft") OR (MH "Travel+"))

Avery index to architectural periodicals

(disab* OR "special need*" OR incapacit* OR "physical disorder*" OR "reduced mobility" OR "physical* challenge*" OR (DE "People with disabilities") OR (DE "Public health") OR (DE"Architecture and the physically handicapped") OR visual* impair* OR vision OR blind* OR "deaf*" OR hearing* OR (DE "Hearing impaired") OR (DE "Visually impaired") OR intellectual OR "mental* deficienc*" OR "Developmental" OR "mental* ill*" OR "mental* disorder**" OR "mental* health disorder*" OR "psychiatric disorder*" OR "psychiatr* ill*" OR neurodivergen* OR neuro-divergen* OR autism OR autistic OR cognitive OR dementia OR (DE "Autism") OR elder* OR older OR senior OR aged OR (DE "Aged") OR Obes* OR (DE "Obesity")) AND (modif* OR "access* program*" OR "access* measure*" OR "universal access*" OR design* OR "assistive technolog*" OR "architectur* access*" OR adapt* OR Signage OR (DE "Universal design") OR (DE "Barrier-free design") OR Inclusiv* OR discriminat* OR Respect* OR Equity OR Justice OR tolerance OR prejudice OR (DE "Social justice") OR Guideline* OR Framework" OR "Frame of reference" OR "Best practice*" OR recommendation* OR polic* OR Rule* OR Regulation* OR (DE "Government policy") OR ((Neutral* OR equity) AND [bathroom* OR restroom* OR Utilit* OR Facilit* OR (DE "Rest rooms")]) AND (Accessib* OR Orientation OR Mobil* OR (DE "Access) OR (DE "Access to airports") OR inclusiv* OR participation OR (DE "Citizen participation") OR (DE "User-centered system design") OR use OR usability OR utilization OR capab* OR capacity OR ability OR adequacy OR appropriateness OR experience) AND (airport* OR "air transport*" OR "airline*" OR aircraft OR (DE "Choice of transportation") OR (DE "Airports—Buildings"))

Web of science

(disab* OR "special need*" OR incapacit* OR "physical disorder*" OR "reduced mobility" OR "physical* challenge*" OR visual* impair*

OR vision OR blind* OR "deaf*" OR hearing* OR intellectual OR "mental* deficienc*" OR "Developmental" OR "mental* ill*" OR "mental* disorder**" OR "mental* health disorder*" OR "psychiatric disorder*" OR "psychiatr* ill*" OR neurodivergen* OR neuro-divergen* OR autism OR autistic OR cognitive OR dementia OR elder* OR older OR senior OR aged OR Obes*) AND (modif* OR "access* program*" OR "access* measure*" OR "universal access*" OR design* OR "assistive technolog*" OR "architectur* access*" OR adapt* OR Signage OR Inclusiv* OR discriminat* OR Respect* OR Equity OR Justice OR tolerance OR prejudice OR Guideline* OR Framework" OR "Frame or reference" OR "Best practice*" OR recommendation* OR polic* OR Rule* OR Regulation*) OR ((Neutral* OR Equity) AND (bathroom* OR restroom* OR Utilit* OR Facilit*))) AND (Accessibility OR Orientation OR Mobil* OR inclusiv* OR participation OR use OR usability OR utilization OR capab* OR capacity OR ability OR adequacy OR appropriateness OR experience) AND (airport* OR "air transport*" OR "airline*" OR aircraft)

Appendix B: Airports' websites free search terms

Disability/ies	Special	Impairment/impaired	Needs
Older/old/aged	obesity	Access	Accessibility
Assistance	Assistive	Accommodation/accommodate	Equity
Inclusive/vity	Discrimination	Help	Customer service
Service.S	Mobility	Wayfinding	Complaint

Appendix C: data extraction grid sample (excel)

The following table contains some non-exhaustive examples of data extracted for a scientific article, for illustrative purposes.

Reviewer name	DG
Title	Airports and ageing passengers: A study of the UK
Authors	Anne Graham, Lucy Budd, Stephen Ison, Andrew Timmis
Year	2019
Study location	UK
Study objective	(…) the aim of this paper is to undertake an exploratory analysis of ageing passengers at UK airports.
Study design	Case study
Population	Older adults
Needs addressed (explicitly in the text)	much of the extant literature on transport and ageing focuses on driving cessation, public transport use and the role of active travel in supporting healthy older age (…) while the impacts of ageing on air travel are hitherto comparatively unexplored.
Purpose of the practice(s) described	N/A
Micro (factors and practices)	(…) Age-related hearing and sight loss, as well as mobility and cognitive impairments, can create challenges associated with navigating new environments and negotiating the procedural logic of air travel, while advances in airport automation may generate anxiety and confusion among an older generation who have not grown up with the technologies and who are consequently not familiar with their purpose and operation. (…) allegations of pre-booked assistance failing to meet user needs, inappropriate equipment, inadequate staffing levels and poor customer service standards often reported (Buckley, 2017). […]
Meso (factors and practices)	In the United States, the Transportation Security Administration (TSA) (2019) has introduced special security screening protocols for passengers aged 75 and over which negates the need for older travellers to divest of shoes and clothing during the security search. (…) priority boarding and disembarkation from the aircraft In response, some airports are seeking to become ,"Dementia Friends" by providing staff with additional training and providing lanyards to allow customers self-identity if they think they would benefit from additional support. […]
Macro (factors and practices)	Within the European Union, all passengers with a disability (whether physical, cognitive or communicative) or reduced mobility (irrespective of age) are legally entitled to support or "Special Assistance" whilst travelling by land, water and air. EC Regulation 1107/2006 states that all EU airports handling over 150,000 passengers a year must provide, free of charge, help and assistance to wheelchair users, older and elderly travellers, and those with communication, social interaction and "hidden" disabilities including autism and dementia. […]
Link to participation (if any)	the latest CAA tracker consumer survey found that 43% of the passengers who requested assistance on their last trip did so for the first time (CAA, 2019b). This survey found that 76%. Those receiving assistance were very satisfied or fairly satisfied with services at the UK airport on departure, and 69% on their arrival back, but satisfaction with the overall flying experience for those with disabilities had decreased from 82% in 2016 to 77% in 2019 (compared to 90% to 81% for the total market) […]
Disability perspective (term used, person or disability centric)	There is a popular misconception that the ageing traveller market consists of frail old people in wheelchairs or with walking sticks. This is incorrect, especially as these travellers make up a number of diverse and heterogeneous consumer groups (Nielsen 2014; Alén et al, 2016).
Research team member reflections and comments	The authors directly support the next steps of our project: "An important area for future work would include in-depth qualitative studies of senior passengers' experiences of using airports. This would provide both much needed and valuable insight into their needs and a greater understanding of the behaviour of this passenger segment."

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Enhancing shared street accessibility in heritage sites for individuals with visual disabilities: a Canadian perspective

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Introduction: Heritage sites often pose significant accessibility challenges for individuals with visual disabilities due to their preserved architectural features and strict regulations against modifications. In shared streets, designed to encourage pedestrian use and reduce vehicle dominance, these challenges are exacerbated by the lack of tactile and directional cues for visually impaired users. This study, set in the context of Canadian heritage sites, explores how shared streets can be adapted to be more inclusive while respecting the integrity of historical environments.
Objective: The objective of this study is to explore and propose practical solutions to enhance the accessibility of shared streets for individuals with visual disabilities within heritage sites, with a particular focus on preservation requirements.
Methodology: The study adopts a three-phase methodology. First, co-design sessions were conducted with three groups of stakeholders: people with disabilities, caregivers, and experts in accessibility and heritage preservation. Second, a narrative literature review was undertaken to identify practices from existing research and urban planning cases. Finally, solutions were developed in collaboration with a design firm to create practical, adaptable prototypes that address the specific needs identified in earlier phases.
Findings: The co-design sessions revealed several key challenges, including the lack of tactile references, difficulties with snow removal, and the need for clearer delineation between pedestrian and vehicular zones. Solutions such as tactile paving, modular bollards, and the use of contrasting materials were developed to address these issues. The narrative review reinforced the importance of universal design in heritage contexts and provided insights into successful implementations in other urban settings.
Conclusion: The study concludes that shared streets can be made more accessible for individuals with visual disabilities by adopting a modular design approach that integrates tactile cues and adaptable urban furniture. These solutions ensure that accessibility and safety can coexist with heritage preservation, promoting inclusivity in public spaces. The research highlights the importance of stakeholder engagement in the design process and offers a replicable framework for improving accessibility in heritage sites globally. However, further field testing is needed to assess the feasibility and acceptance of these solutions within the regulatory constraints of heritage environments.

KEYWORDS

visual disability, shared street, accessibility, active transportation, public space, mobility, equity, active design

1 Introduction

Heritage contexts pose significant challenges for people with visual disabilities. This is largely due to uneven surfaces and high or narrow steps or pavements. Many of these sites are protected by strict laws, depending on the country, which prevent modifications that would improve accessibility. For example, in Quebec City, Canada, in order to make an intervention to make the physical environment more accessible authorization is required from the Ministère de la Culture et des Communications du Québec and certain responsibilities are delegated to the city. The process is lengthy and if the proposed modification is likely to have an aesthetic impact on the buildings surrounding and within the heritage context, there is a significant probability that the proposal will be rejected (1). This is where shared streets emerge as a promising solution to address accessibility issues, by reconfiguring the street layout to create more uniform surfaces and eliminating traditional sidewalks.

Shared streets, accessibility for people with visual disabilities and heritage sites are three elements that continue to have problems in blending well together. On one hand, we have the shared streets that were originally intended to give a greater importance to the pedestrian (2), which had been completely forgotten by the presence of the car. The idea was to create a space where all street users could coexist harmoniously, primarily by significantly reducing the speed to 30 km/h, since the default and common speed limit on local streets in Canada is 50 km/h (3). A significant amount of research has been carried out to assess the effectiveness of shared streets and their impact on the mobility, safety and quality of life of road users, since these types of streets are usually accessible for people with motor disabilities, since there are no physical barriers such as the sidewalk (4, 5). Reducing car dominance on shared streets promotes social interaction, increases physical activity for pedestrians and cyclists, and reduces the number and severity of road collisions (6).

Blind people on shared streets lack tactile and directional cues (7). Raised sidewalks, which often serve as a physical separation between different traffic zones, may be absent or less perceptible on shared streets. This can cause confusion, reduce confidence, and increase anxiety for pedestrians with visual disabilities (8). In addition, ground markings such as crosswalks or wayfinding strips may be insufficiently contrasting, making navigation difficult for them. In Nordic regions in particular, it is essential to carefully choose the material of tactile surfaces to ensure their durability. For example, although rubber may seem promising, it is not suitable due to its vulnerability to winter conditions (9).

Despite the accessibility success of shared streets for individuals with motor disabilities, and the existing research to improve the design practice of accessible streets (4, 5) many fail to explore some potential solutions to address inclusion for the visually disabled. Thus, the main objective of this manuscript is to deepen our understanding of the challenges and opportunities of shared streets, through people with disabilities perspective, specially people with visual disabilities and to explore possible venues of universal solutions, including the visually disabled. We intentionally chose to delve deeper into the experiences and perceptions of safety among individuals with visual impairments. This focus was due to the relative lack of attention and documentation in existing literature on how such individuals navigate and feel secure in these environments, compared to other types of disabilities

To address these challenges, a "universal design approach" was adopted in this study. This approach is further examined in subsequent stages, as outlined in the article titled *Preserving the Past, Embracing the Future: Co-Design Strategies for Achieving Harmony between Heritage Sites and Accessibility Needs*, which provides a more detailed analysis of the intersection between accessibility and heritage preservation, and explores co-design strategies as a means to achieve a balance between maintaining historical integrity and enhancing accessibility for all.

2 Methodology

To meet the objective of this article, the methodology is divided into 3 phases: Phase 1- Three co-design sessions with different key stakeholders were organized to identify the challenges and opportunities (10) of shared streets and explore possible solutions; Phase 2- A narrative literature review in databases and on the Internet was done, to find best practices regarding the points identified in the previous phase; phase 3- Developing solutions with the help of a design firm that was integrated to the team, based on what was found to be best practices.

2.1 Phase 1: co-design sessions

The three co-design sessions took place at Centre interdisciplinaire de recherche en réadaptation (Cirris; Québec, Canada) within 2 weeks between one another. The average duration of each session was 2 h, and each was organized for a different type of subject expert, (1) participants with different disabilities, (2) caregivers, and (3) experts in accessibility, heritage and architecture.

Participants for the first session were adults with disabilities responding to the following selection criteria: to live with a visible (physical, visual, normal aging process related) or invisible disability (autism, intellectual disability, hearing disability, chronic pain or fatigue); to be 18 or older; and to be able to communicate with the research team with or without aids or support. Snowball and convenience sampling was carried out. Several organizations related to the targeted disabilities (e.g., *Regroupement d'Organismes de Personnes Handicapées de la region 03*—ROP 03) participated to the recruitment process. Participants who had expressed an interest in taking part in the study and had previously been involved in another stage of the project were contacted by telephone to determine their eligibility, as this topic is part of a larger, more extensive project.

The second session aimed to gather caregivers of another person with any kind of disability, being adults and being able to communicate verbally. They were recruited through the participants of the previous steps of the project.

Finally, participants for the third session, included experts with a minimum of 5 years of experience working on heritage buildings.

The place that was chosen to contextualize the accessibility problems was the Champlain District at the Old Quebec in Quebec City, Canada (https://www.quebec-cite.com/en/old-quebec-city) and streets such as Saint-Joseph that includes some heritage buildings. The reason for choosing this heritage site was because it is one of the most important site in Canada and the research team is well familiar with the environment due to another project developed previously entitled *Experiencing accessibility of historical heritage places with individuals living with visible and invisible disabilities* (11).

The "starting point" for the discussion in the three sessions was Exhibition Road in London, UK (https://www.gardenvisit.com/gardens/exhibition_road_south_kensington), as an example of shared street. This street stands out for the fact that it is entirely on one level, offering a shared space for every type of road user (pedestrians, cyclists and vehicle drivers). Limiting vehicle speeds to 30 km/h helps reduce the risk of accidents, and promotes a soothing urban atmosphere (3).

Each session started by explaining the characteristics of the concept of the shared street, showing several pictures and examples found on the internet. Afterwards, participants were given the opportunity to express their views and the first author opened the floor to suggestions and ideas for improving accessibility, such as regular surfaces to circulate, among others. Since the needs and recommendations of blind people emerged relatively quickly in each session, the second author would start synthesizing the participants' ideas from their descriptions and draw them in a flipchart in front of everyone, in order to validate the idea and, for the rest of the participants, to understand the idea and being able to enrich it. This process would continue until the idea took on a solid, well-founded form.

All sessions were recorded and structured according to a uniform outline. The comments and solutions mentioned in the first co-design session were taken into account to present them in the second session and so on in the third, in order to enrich and better define the solutions. The research project was presented on a PowerPoint presentation by the first author.

2.2 Phase 2

The elements and solutions identified during the co-design sessions were meticulously organized by the research team to delve deeper into best practices outlined in existing literature and online sources. This process paved the way for a comprehensive narrative review, which characterizes it as an overview of scientific literature on a specific topic, providing a synthesis of available knowledge (12). This method facilitated the integration of recommendations with established knowledge and incorporated received feedback. The selection of articles typically occurs without pre-established inclusion or exclusion criteria, with varying opinions on the use of criteria to assess evidence quality (13–16).

Concurrently, authors initiated the narrative review process by defining a comprehensive set of keywords encompassing various aspects of the topic. These keywords guided systematic searches on databases such as Geobase and Google Scholar, laying the foundation for a thorough exploration of relevant literature. The keywords used for the research included terms like "Visual disability," "Disabilities," "Shared street," "Accessibility," "Active transportation," "Public space," "Mobility," "Equity," "Active design," "Woonerf," "Pedestrian environment," and "Orientation and mobility." All searches were conducted in English.

As we delved deeper, we expanded our search to include grey literature[1] sources, consulting Google and exploring a website called "collectivitesviables.org," which offers a series of articles related to this theme. Specifically, we found a relevant case study titled "Montréal: Concilier rue partagée et accessibilité universelle," available at collectivitesviables.org. This search also uncovered a series of publications discussing topics like slowing down speed and active transportation, particularly relevant given the similar winter conditions between Montreal and Quebec City.

2.3 Phase 3: developing solutions

An industrial design company named "Elabore" was hired, funded by the grant, to develop prototypes. This company was selected for two main reasons, the first one is that one of the owners of the firm is a wheelchair user and due to his lived experience, he has a sensitivity that we can hardly find elsewhere, and the second reason is that one of the employees was involved in the project when he was a student in its initial phase, so the knowledge and awareness of accessibility issues, we found indispensable for the successful development of the project.

After signing a contract, a meeting of at least 1 h was held every week from October 2023 to March 2024. In these sessions, the company's progress was presented, and discussions were held to improve the proposals. In the case of a particular prototype, a full-scale wooden model was built to identify problems and find solutions. This particular session took place on the company premises with both teams, the research team for this article and the company team. After this, some weeks later, the prototypes were built and delivered to the research team.

3 Data analysis

Every co-design session was integrally transcribed by one team member, and the transcripts were revised by the first author (ML). A simple thematic analyses were conducted by associating the different solutions that were commented and commented again

[1]Grey literature: refers to materials and research produced by organizations, governments, academia, or industry that are not formally published through traditional commercial or academic publishing channels. These documents are often not subjected to rigorous peer review, which is a key distinction from more formal academic publications.

in each session. This type of analysis is recommended for exploratory studies where data is limited (17, 18). A similar approach was taken for the narrative review, meaning that the most important themes that emerged from the different sources were identified and regrouped.

These solutions from the co-design sessions were then compared to the results found in the narrative review.

3.1 Ethics

The study was approved by the sectorial ethics committee on research in rehabilitation and social integration of the *Centre Intégré Universitaire de Santé et de Services Sociaux de la Capitale-Nationale* (#2022–2422) and every participant signed a consent form.

4 Results

4.1 Co-design sessions

4.1.1 First session

Seven participants ($n = 7$) were involved and presented different disabilities 2 participants with physical disabilities (P1 and P2), 1 person with visual disability P3, 1 deaf person P4, 1 person with autism spectrum disorder P5, 1 person with intellectual disability P6, and 1 elderly person P7, allowing for a variety of perspectives.

The proposal for shared streets, using London's Exhibition Road as an example, sparked lively debate. The idea offered a promising vision for meeting the needs of people with disabilities, while improving the usability of urban space for all citizens. However, it was noted that specific adjustments would need to be made to fit to the Champlain's District at the Old Quebec context. For example, a participant P1 in a wheelchair asked: "*Could ice be forming on the drain, complicating the situation?*" which extended the debate to the possibility of heating the drain, which would be beneficial in preventing snow accumulation in winter, but this option comes with significant costs.

Feedback from participants was essential to clarify that the shared streets solution did not include a recess for the drain, but rather a smooth surface. In addition, the use of sandstone with a fine joint for the cladding was emphasized to minimize shaking during movement. A pertinent question was posed by a participant P3 with visual disability: "*If it's flat, how does a blind person get around safely?*"

Concerns were raised by P3 about the practicality of snow removal, with the participant noting, "*It's good for snow removal, but there's a concern about the drains that could block the wheelchair wheels.*" This observation underscored the importance of a smooth surface, on the same point, P1 added: "*Well, for me, it was just… I think it's really great [laughs], but I know one thing, it's that since these are stones, we need to make sure that the distances… you know, that there aren't any cracks between each stone because in a wheelchair, it's bump after bump after bump, and it's bad for… well, it hurts me a lot. I know that most people also have back pain because of that*", leading to the decision to include raised tactile tiles strips on streets to guide the person with visual disability safely and to implement bollards to provide a sense of security. Additionally, the potential for climate change to reduce the costs of such implementations was discussed, as P3 remarked, "*With climate change, it's going to become less and less expensive…*"

If we can summarize the most important results of the first session, two main themes that emerged from the first session were winter and snow removal, as well as the need for more tactile references for blind individuals. It is important to bare in mid the context in which this research was developed. Quebec City receives more than 3 m of snow every winter, so it is not surprising that one of the biggest concerns for people with disabilities is precisely the snow.

4.1.2 Second session

The second co-design session, 4 family caregivers participated, and special attention was given to their contribution as they provided an additional valuable perspective. As daily supporters of people with disabilities, they offer a unique insight into real and practical needs. This helps develop more suitable solutions by considering both the expectations of the individuals being assisted and the challenges faced by their caregivers.

The two main issues that came up in the previous session (snow removal & tactile references) were addressed by the research team and a proposal of solution was included in the presentation.

A caregiver of a person in a wheelchair (P1) highlighted the challenge faced by wheelchair users in such weather conditions, emphasizing the need for a solution like vertical wrist handles to ease maneuverability. The observation was that the addition of a handrail could considerably ease the passage of wheelchair users by providing extra support, as shown in the figure below, P1: "*For the ramps, if we could also add some handles because usually, it's like full of snow and the bars… It's hard to grab with your hand. A vertical handle could help because it's for someone in a wheelchair*". However, the delicate issue of winter and snow quickly emerged. It was pointed out that the handrails were likely to be covered in snow, making them difficult to use. After some debate, an emerging solution was proposed: integrate vertical supports on the handrails, thus limiting snow accumulation (Figures 1, 2). This idea would maintain the handrails' functionality throughout the winter, ensuring easier and safer access for people with reduced mobility in Old Quebec. This idea underlining the need to think about practical, ergonomic devices to ensure unhindered mobility.

The thorny issue of winter snow management was addressed, with the proposal of an innovative solution inspired by Iceland, which exploits geothermal energy to heat certain sections of sidewalk. A proposal was made to incorporate a transparent coating for ground leveling without obscuring the tiles. "*For sidewalks with floor tiles, a substance can be added to flatten the*

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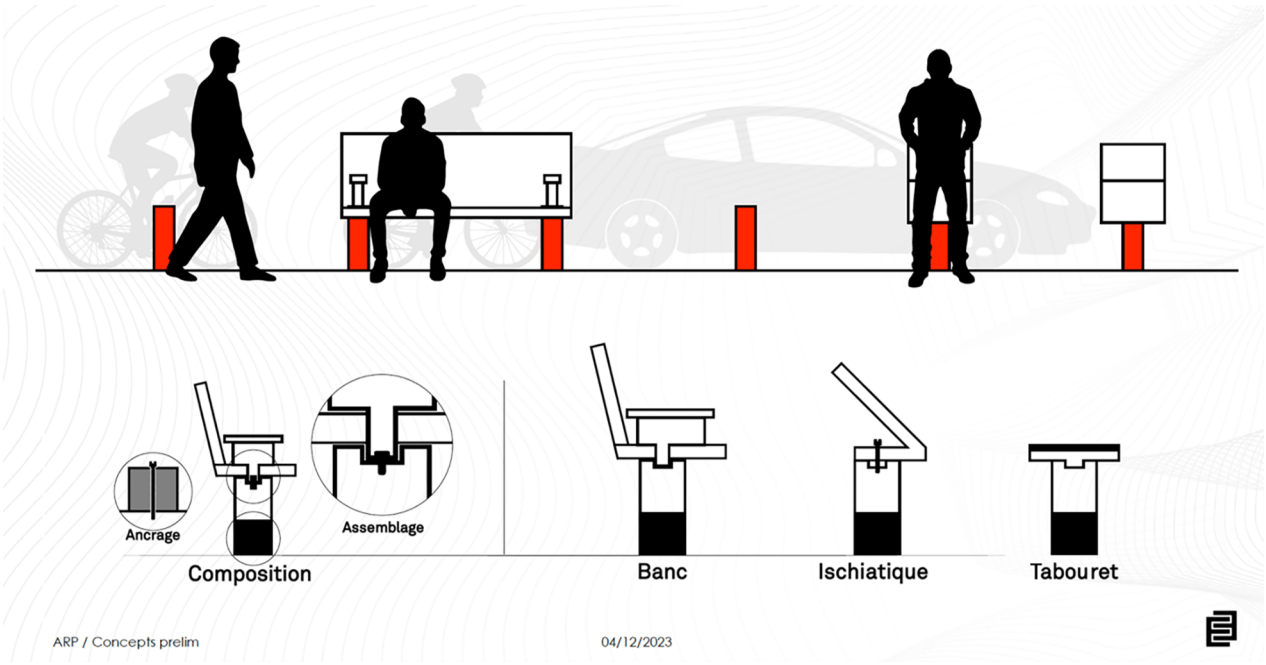

FIGURE 1
Elevation section explaining the Lego concept.

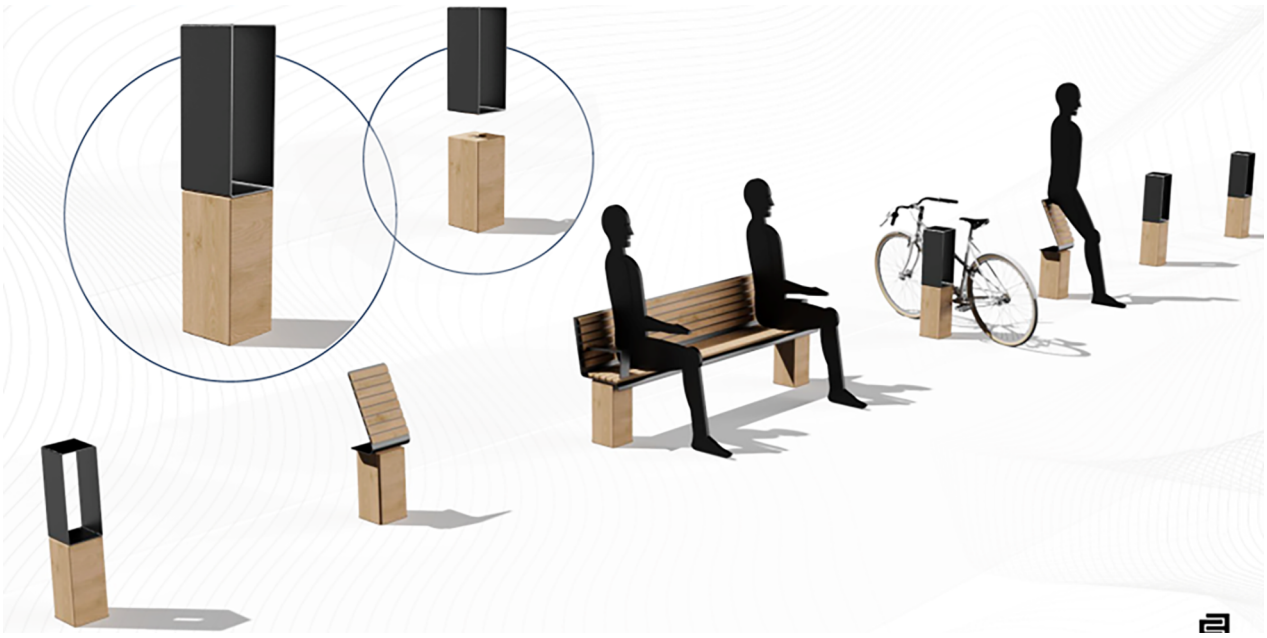

FIGURE 2
Oblique view of the concept.

floor without masking it" said P1 creating a link with previous considerations on street surfaces.

P2 who is a second caregiver of another person in a wheelchair said: "*We can also work with… I would say paving stone, anti-slip stone but with a joint that is like 1 mm so that it doesn't stir.*" By using anti-slip stones with minimal joints, they aimed to mitigate the risk of displacement or tripping hazards, ensuring a smoother and safer walking surface. However, this solution was

not popular, because the concern was about removing everything and replacing it with new sandstone, which would be expensive.

To enhance inclusivity, some participants suggested engraving grooves in the pavement to serve as tactile strips, guiding the walking sticks of blind individuals and making navigation easier.

The accessibility of bus stations was also discussed, using the example of the Place d'Youville[2] station as an illustration of the importance of making all stations accessible, especially for wheelchair users. P1: "*Okay. the most important thing, is to make all the bus stations accessible because …. my friend, sometimes he doesn't go out into the city just because, for example… the d'Youville station isn't accessible. So it's a lot of walking to get down to these places.*"

The potential benefits of heated sidewalks were highlighted, alongside the idea of signage on solar-heated metal surfaces, suggesting an innovative approach to making urban spaces more comfortable in all seasons. However, it's not a proposal feasible in the Quebec context, as a northern country where snow takes up a lot of space and heating with electricity would be very expensive and in Quebec there are no alternative options such as geotherm or solar panels as there is not that much sun in wintertime.

The same themes from the first session were discussed again in the second session (winter, providing better references for blind people on the street), this time with a wider range of potential solutions.

4.1.3 Third session

During our third co-design session, a sample of $n = 7$ experts with diversified skills, from different disciplinary spheres. These experts, came together to assess the viability and relevance of the ideas co-created in the previous phase.

The experts selected came from different backgrounds such as architecture, heritage and accessibility. Their practical experience of working with people living with disabilities was also a came as a valued asset. What's more, some of the experts were direct representatives of the sites concerned, bringing a relevant and concrete perspective to the discussions from the point of view of workers, managers and owners.

P1, who is an occupational therapist, expressed her initial impression regarding shared streets, stating, "*Blind individuals often experience a lot of discomfort on shared streets.*" This perspective highlights the challenges faced by visually impaired people in navigating urban environments that do not adequately accommodate their needs, emphasizing the importance of designing inclusive spaces that prioritize accessibility and comfort for all users.

Some participants (P2 and P5) who are respectively a professor of architecture at the faculty of architecture at Laval university and an architect raised the idea of removing sidewalks to bring heritage sites closer to the past, referring to the fact that at a time when horses reigned supreme, there were no sidewalks. They also suggested that this approach would be easy and gradual, stressing that it was a simple solution, if not a strategy. However, concerns were expressed about snow clearance on streets without sidewalks by a disability advisor at Laval University (P3), and the potential problems associated with the restaurant and bar terraces that currently occupy these spaces was raised by the representative of the merchants of Petit Champlain Street (P6).

In addition, the issue of cyclists was raised by an occupational therapist (P1), with the idea that they can be perceived as an additional challenge on shared streets, and proposals to introduce guides or maps to orient people were made. The session also highlighted specific situations where compromises have to be found, notably about emergency situations (P5) and the need for crossings to reach sidewalks on one side (P1). The issue of changing the street level was raised, warning of the potential impact on building structure (P2).

The perspective of blind people was put forward (P1), pointing out that tactile cues are not sufficient and that eliminating sidewalks would add a significant burden for blind people, causing a sense of insecurity. It was suggested that adding gradients (P3) might be a more appropriate solution, and the idea of projecting routes in winter to increase contrast on the street was mentioned (IF). Some participants noted that familiarization with this solution, combined with appropriate signage, could facilitate its acceptance. Some new ideas came up, for example, to put 2 podotactile strips, instead of one, to show the boundary of the pedestrian zone. One at the side of the buildings and the other at the boundary for cyclists or motorists. In the same way it was suggested to use street furniture to increase the references for blind people.

With regard to snow, it was suggested that some street furniture could be easily removed in winter to facilitate the task of snow removal.

4.2 Narrative review

A total of 110 sources, including articles and reports, were consulted. This review encapsulated comprehensive insights into various aspects, highlighting key findings in the areas of pedestrian and cycling delineation, surface coating, signage and lighting, and urban furniture. These topics provided a comprehensive understanding of the considerations and recommendations associated with creating accessible and well-designed environments. The diverse range of sources accessed through Google Scholar and Geobase enabled us to construct a framework for addressing the complexities of urban planning and design in relation to accessibility and mobility.

We selected articles dating from 2000 to 2023 to gain insight into discoveries made over the past decades, with the most recent

[2]Place d'Youville in Quebec City is a square located in Old Quebec. It's a lively place with cultural activities and restaurants, and is surrounded by the historical atmosphere of Old Quebec.
It presents accessibility challenges due to its elevated location, steep slopes and cobblestone streets. These features can make access difficult for people with disabilities, requiring special attention to access and travel planning.

research retained dating back to 2005. The following paragraphs describe the most recurring themes mentioned in the various sources of the review, along with those that resonated most with the results of the co-design sessions.

4.2.1 Delineation of pedestrian and cycling

A recognizable structure that clearly indicate places designated for walking and crossings were identified as essentials. This recognition relies on the coherence and predictability of the environment, characterized by elements with specific meaning and function. Thus, each potential destination should be accessible through a recognizable, obstacle-free, and uninterrupted path, ensuring navigation without confusion (19). To ensure effective separation between the pedestrian zone and the roadway, as well as the cycling lane, protective strips with a minimum width of 60 cm can be utilized. These strips should be tactile, allowing identification using a detection cane or foot, for example, using a green strip (9).

4.2.2 Surface coating

The material for tactile surfaces must be thoughtfully chosen, especially in Nordic countries, to ensure good durability. The coating material is non-slip under all weather conditions, does not produce reflections, and minimizes glare. There should be no space between the pavers or slabs (20). To this end, the coating must not have holes, gaps, or other deformations, and there should be no steps exceeding 13 mm (Advisory Committee on Universal Accessibility, 2014). A British report emphasizes the importance of surface drainage to prevent water accumulation. It recommends the installation of linear drains along tactile delineators (21). The careful consideration of these coating specifications ensures not only the longevity of the material but also the safety and accessibility of the environment, particularly in adverse weather conditions.

4.2.3 Signage and lighting

The illumination should be sufficient, activated as needed, arranged in a thoughtful and consistent manner, and avoid any light pollution. For instance, employing a combination of streetlamps and urban furniture can be utilized to physically mark the separation between pedestrian and vehicular areas (19). Signage should be easily visible for individuals with residual vision and should be designed with high contrast and large characters (22). The entrance and exit of a shared street must be clearly recognizable and announced in a straightforward manner (23). The installation of two-dimensional tactile maps (with raised points adhering to specific standards) or three-dimensional maps (in the form of models) can greatly enhance the understanding of an unfamiliar environment by facilitating mental representation (24). Bollards or poles could serve as carriers of tactile navigation assistance information, particularly to indicate the direction and relative distance to the nearest crossing point (25).

4.2.4 An imaginary tunnel

When setting up a pedestrian corridor marked by street furniture, it's important to follow certain guidelines to optimize accessibility. According to the study titled *Clinical Programming 2022 Institut Nazareth et Louis Braille: Final Report* (26), furniture components should not be separated by more than 1.2 m, thus promoting a coherent, unobstructed path. In addition, the lighting of these elements proves essential to enable visual discrimination for people with visual residuals, in line with the recommendations of Parkin and Smithies (27). As far as planting areas are concerned, they require particular attention to avoid encroaching on the pedestrian corridor. As stated in the study titled *Clinical Programming 2022 Institut Nazareth et Louis Braille: Final Report* (26) they should have a minimum width of 1.2 m where trees are present, or 0.6 m in other cases. In addition, the planting pit must be level with the pedestrian corridor, with a maximum difference of 6 mm, and plantings must be regularly maintained.

4.2.5 Urban furniture

Street furniture components must be designed to be detectable with the cane, following the concept of the "imaginary tunnel" evoked by some authors such as Isler, Dejeammes and Hallet (28). Thus, careful planning is required to define a sufficient volume to allow an obstacle-free path for the visually disabled. Urban furniture encompasses various elements such as fountain posts, parking meters, benches, bus stops, poles, bike racks, waste bins, and planting zones. When the pedestrian corridor is marked by urban furniture, the components of the furniture should not be separated by a distance of more than 1.2 m (29). Additionally, they should be illuminated to allow discrimination by individuals with residual vision (27). Every component of equipment or urban furniture must be detectable with a cane. Some authors refer to the concept of an "imaginary tunnel" originating from Barcelona to keep in mind the necessary volume delineating an obstacle-free path (28). Planting zones should not encroach on the pedestrian corridor. Hence, they must have a minimum width of 1.2 m when including trees or 0.6 m in other cases. Additionally, the planting pit should be at the same level as the pedestrian corridor or with a maximum difference of 6 mm, and the plantations require regular maintenance (29).

4.2.6 Maintenance and seasonal conditions

A Quebec study involving 24 individuals with visual disabilities and 12 orientation and mobility specialists found that warning tiles made of polymer (Armor-tile) or stainless steel (Advantage) remained detectable underfoot in winter conditions in sunny areas. Armor-tile achieved the highest detectability score. However, the authors note certain nuances: the impact of color on detectability could not be satisfactorily analyzed, and the study in semi-controlled conditions would benefit from being complemented by a study in real conditions where the tiles would undergo regular maintenance such as snow removal and abrasive spreading (30, 31).

4.3 Developing prototypes

With the different results found in the co-design sessions and the narrative review, it was decided to try to create a proposal

including as many of the results as possible. However, the most important emphasis was put on the creation of shared street elements to promote a feeling of safety for visually disabled people. Therefore, our proposal revolves around the design of a shared street that do not share areas and where the three lanes—bicycle, pedestrian and car—cohabit at the same level (no difference between sidewalk and road) but are clearly identified. In order to address the specific concerns of the visually disabled, we suggest the integration of removable bollards. These will play a crucial role as a physical barrier, while scrupulously respecting White's requirements, notably by avoiding the use of materials that generate a dazzling effect (20).

As part of our collaborative teamwork, we set about synthesizing our ideas, taking into account the constraints inherent in the urban context, as well as the various needs of users, with particular emphasis on the challenges posed by harsh winters. The solution that emerged from this process is a "modular concept" or "LEGO-like concept" applied to urban planning in cities like Quebec City. This concept features a range of components (pedestrian benches, bollards, signage, barriers to slow down cars and bicycles) that allow for flexibility and customization, enabling the heritage environment to be shaped and adapted harmoniously to local specificities.

5 Discussion

This article aimed to deepen our understanding of the challenges and opportunities of shared streets, through the perspective of PWD and to explore possible venues of universal solutions that fulfilled the needs of visually disabled individuals. The results from the co-design sessions and the narrative review align in recognizing the challenge of blind or visually disabled pedestrians circulating in shared streets. Navigating in an unfamiliar or atypical environment increases the cognitive load for any pedestrian. While sighted pedestrians can compensate for this load with visual cues at their disposal, visually disabled pedestrians may optimize the auditory and perceptual information available (32). This unf is more palpable in environments where design features are not uniformly comprehensible to these individuals. Obstacles, such as the absence of visual cues, clear demarcation between spaces intended for cyclists and pedestrians, insufficient signage at street corners and crossings, and the non-existence of dedicated crossing zones, were identified (33, 34), promoting a feeling of insecurity. However, the results of both, narrative review and co-design sessions, shed light in contributing to pedestrians' comfort by reducing traffic volume and speed (35). Nevertheless, the claim that the reduction of demarcations alone decreases traffic speed lacks empirical support and requires further discussion.

In most cases, the average vehicle speed diminishes in shared streets with higher pedestrian density, aligning with the goals of such zones. Nevertheless, it's crucial to consider factors such as eye contact, as highlighted in the study by Karndacharuk, Wilson, and Dunn (36), raising awareness that auditory information from traffic might diminish in these configurations. Additionally, the advent of quieter electric or hybrid vehicles presents a new challenge for visually disabled individuals (Canadian Council of Physical Transport Administrators, 2013; 32). Thus, the discussion on shared streets should encompass the multifaceted aspects of traffic reduction and the evolving landscape of vehicle technology.

Another aspect that converged in the narrative review and the co-design sessions was incorporating differences in color, materials, or a slight gradient in crossing zones that can effectively encourage motorists and cyclists to reduce speed and exercise greater caution. Additionally, strategically narrowing the road at specific spots can naturally induce a reduction in speed, aligning with the recommendations of Havik and Melis-Dankers (19).

There were some elements that the co-design sessions did not covered and the narrative review complemented and helped to have a better understanding. For example, additional elements that need to be taken into consideration such as having an adequate path that remains intrinsically conditioned by its continuity, the visibility inherent in its routes, its safety and comfort, while taking into account accessibility-related aspects (37). According to the recommendations of the Comité consultatif en accessibilité universelle (38) from the Provincial Government of Quebec, a pedestrian corridor should be characterized by its straightness and continuity, avoiding any potential obstacle forcing the pedestrian to deviate from his or her trajectory. Yet even with such a path, the indicators for entering and exiting a meeting zone frequently remain insufficient, as Havik et al. (16) and Melis-Dankers et al. (39) have pointed out. In particular, a clear tactile demarcation between sidewalk and sidewalk is a fundamental requirement.

On the other hand, the co-design sessions shed light into the fact that if we opt for the installation of specific lanes and paths dedicated to each type of road user, there is still a risk that cars will dominate the space and not feel obliged to slow down or share the road fairly. This approach could compromise the safety of other road users, such as pedestrians, cyclists and people with reduced mobility, who could find themselves in conflict with vehicles. Moreover, implementing a shared street in a Nordic City may increase some safety issues. There are multiple concerns: drivers' adaptation to an approach devoid of visual cues, the risk of vehicles dominating specific lanes, and the potential conflict with the aesthetics and integrity of heritage sites. Rigorous analysis of these considerations is imperative to ensure the safety, accessibility and preservation of sites and road users.

By adopting the shared street strategy, we aim to create an environment where pedestrians have a decisive influence on traffic flow. However, for this approach to be effective and following the line of thought of the participants in session 1, it's essential that the crossing zone is clearly identifiable and discernible, thanks to visual and tactile cues. A precise direction must be indicated, enabling visually disabled people to easily locate the beginning and end of the crossing zone, as well as the guidance line indicating the path to follow. These tangible markers are an ideal replacement for the perpendicular kerb that visually disabled people generally use to cross in a straight line.

This approach, advocated by Havik and Melis-Dankers (19), aims to create a safer and more intuitive crossing experience for visually disabled pedestrians.

After in-depth discussions and careful analysis of the data collected, and despite the warnings in the narrative review highlighting the potential risks associated with bollards for the visually disabled, our proposal is based on an approach carefully adapted to the Quebec context, particularly the heritage and winter ones. Mindful of White's recommendations that bollards are often considered the most dangerous elements of street furniture for visually disabled individuals, we advocate an innovative solution (20).

The modular approach enables urban design to be conceived as a creative and evolutionary process. This methodology offers an accessible and adaptable solution for heritage environments, particularly for northern cities like the Old Quebec City. By envisioning the urban site as a green base, the pieces become a metaphor for street furniture and landscaping. As in the construction of a modular structure, these elements can be added, shaped and installed to optimize the opportunities offered by the site. This approach promises a grounded approach to to respond to the complex requirements of urban design, integrating climatic imperatives and the varied needs of users.

It should be stressed that this approach goes beyond simply separating traffic flows. We see these bollards as modular elements, reminiscent of the "LEGO-like concept" in which you can interchange "pieces" in order to better adapt to the physical context of the street responding at the same time with pedestrians (visually disabled or not). This flexibility would enable the urban space to be dynamically adjusted to the changing needs of the community. Referring to the work of White, who advocates a minimum height of 1 m for bollards, as well as adequate visual contrast, our proposal aims to integrate these elements into a versatile system, serving as a base for additions such as benches, buttock rests, bicycle parking facilities, and other functionalities, to create an inclusive and evolving urban environment.

These bollards would act as physical barriers between the different lanes, providing clear and tangible markers for pedestrians, cyclists, and motorists. The introduction of these bollards aims to create an environment where each road user has a clearly delineated space, helping to reduce the risk of conflicts and accidents, providing, at the same time, a feeling of security for the visually disabled.

One of the key features of these bollards is their removability. This design has been carefully thought out to meet the specific climatic requirements of the Quebec context, where snow and winter conditions play a major role. Removable bollards enable snow removal crews and plows to carry out their operations throughout the winter, without impeding traffic flow or compromising safety. This flexibility is crucial for ensuring the year-round practicability of shared streets, accounting for seasonal variations and the weather challenges unique to the region.

By incorporating removable bollards and other urban furniture in shared streets, both the needs of the visually disabled and the practical imperatives of managing public spaces in a demanding winter environment will be taken into account. This measure aims to balance safety, accessibility, and functionality, while ensuring a safe and pleasant experience for all road users, whatever the environmental challenges facing the Quebec region.

5.1 Example of the application of our findings: making Rue Saint-Joseph inclusive

Located in the heart of the Saint-Roch district in Québec, Saint-Joseph Street is a vibrant hub of activity, close to the downtown area. It seamlessly blends the old with the new through its boutiques, restaurants, and cultural spaces, showcasing a successful urban revitalization. Its strategic location makes it easy to explore the various facets of the city, making it a favored spot for both locals and visitors alike. Saint-Joseph Street is synonymous with dynamism and culture, reflecting the lively spirit of Québec. It hosts a variety of shops, restaurants, bars, and cultural venues, offering an interesting mix of old and new. The street plays a significant role in the cultural life of Québec, hosting various events and festivals throughout the year.

We chose Rue Saint-Joseph as a prototype street for its potential to be not only accessible but inclusive for people of all abilities. With its width of 12,000 mm, the street offers ample space to accommodate various types of users, including pedestrians, cyclists, and motorists. This width allows for the implementation of features and designs that prioritize inclusivity, such as widened sidewalks, designated bike lanes, and traffic-calming measures.

Figure 3 shows the current state of Saint-Joseph Street. The image depicts a street with sidewalks on both the right and left sides, with a noticeable absence of clear demarcation or a safe zone for pedestrians. This lack of defined pedestrian areas highlights the challenges faced in ensuring accessibility and safety for all users.

By selecting Rue Saint-Joseph, we aim to demonstrate how urban spaces can be redesigned to ensure accessibility and inclusivity for everyone, regardless of their mode of transportation or physical abilities.

The two-dimensional proposal illustrated in Figure 4, and the three-dimensional proposal shown in Figure 5, present a more structured street layout with a clearly defined pedestrian zone, featuring bollards to enhance the sense of safety for all types of users within the pedestrian area, as mentioned by the participants of session 1. Tactile paving is present to guide individuals with visual impairments, and the removal of sidewalks aims to offer a more accessible environment for those with mobility impairments. Additionally, a designated parking area is planned to improve accessibility for motorists, making the street more user-friendly for everyone.

However, we had to consider the seasonal installation of outdoor terraces, particularly during the summer months. This installation significantly alters the level of activity, the associated risks, and the flow of traffic on the street. As a result, we made the decision to temporarily exclude the bike lane from this street during these periods. This measure was taken to mitigate the potential increased

FIGURE 3
"Rue Saint-Joseph": the heart of Saint-Roch, Québec.

FIGURE 4
A design proposal for "Rue Saint Joseph".

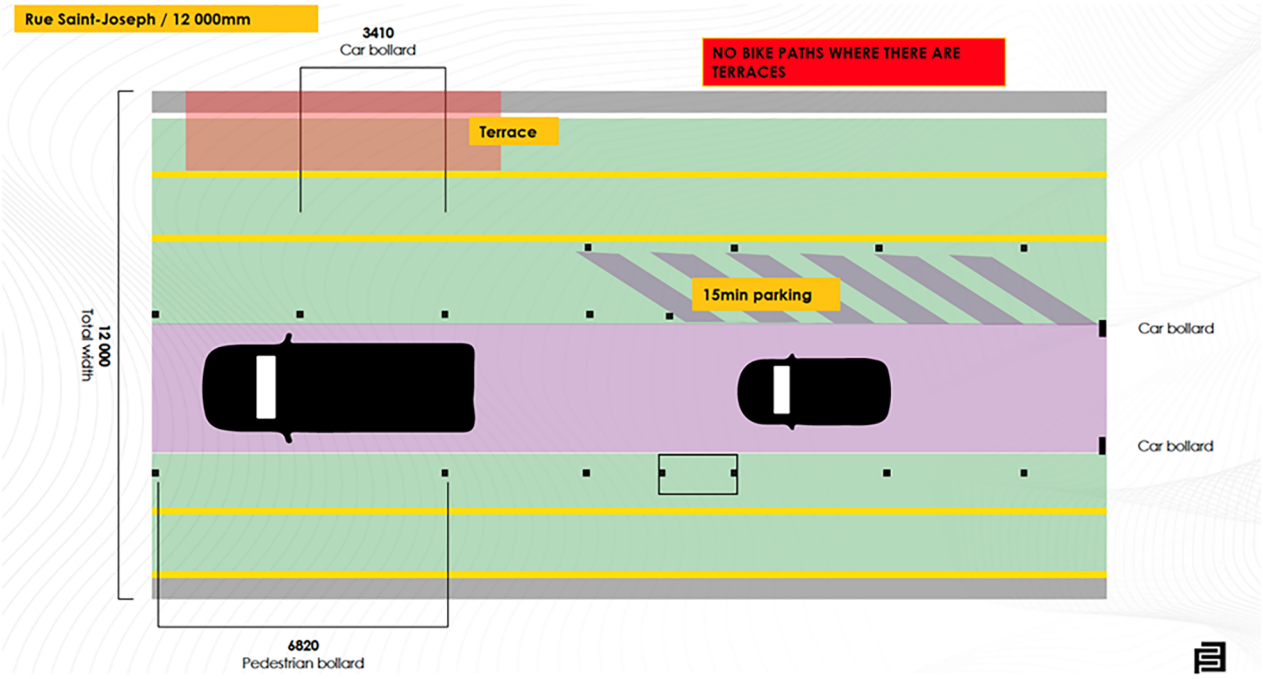

FIGURE 5
Prototype design for the Rue Saint-Joseph.

danger that the bike lane would pose to all users, including restaurant patrons, servers, pedestrians, and even cyclists themselves.

An important limitation of the present study is to test the proposal. We do not know if this proposal will be accepted by the Ministère de la Culture et des Communications du Québec, as it will certainly have an aesthetic impact on the heritage context. However, we wanted to integrate noble materials such as wood and steel for a better integration of the proposal in the context. However, studies such as the present one, may contribute to give guidelines to integrate these solutions in the future.

6 Conclusion

The design of shared streets represents a complex and multifaceted challenge, requiring a holistic approach that integrates the needs of blind and visually disabled pedestrians, road safety requirements and the aesthetic and functional constraints specific to each environment. The concept of "the exhibition road", although successful in London, raises questions as to its transposition to a Quebec context, where the specificities of road behavior and infrastructure diverge. It is imperative to reconcile accessibility requirements for the visually disabled with safety requirements for all road users. The adoption of clear, consistent visual and tactile cues, the provision of continuous, obstacle-free footpaths, and the integration of solutions adapted to local particularities are all prerequisites for ensuring harmonious, safe coexistence.

Implementing a shared street, for example, in the heart of the Petit Champlain district in the Old Quebec or at Saint-Joseph Street, presents considerable practical challenges. Testing such a configuration with people with disabilities raises major concerns in terms of actual accessibility. Shared streets require particular attention to safety and ease of use, especially for people with disabilities. Therefore, while prototypes can offer useful insights, the actual integration of these concepts into real environments requires thorough evaluation and constant adaptation to ensure an inclusive and safe experience for all citizens, regardless of their abilities. However, this model aspires to be an inspiring source for future initiatives, providing a foundation for projects that seek to reconcile universal accessibility with heritage preservation. This vision encourages collaboration among researchers, practitioners, and decision-makers, thereby creating a conducive platform for the emergence of avant-garde solutions in the realm of inclusive urban planning that respects cultural heritage.

Ultimately, striking a balance between accessibility, safety and aesthetics in shared streets within a heritage context remains an ambitious goal. However, it is by adopting an inclusive approach, drawing on international best practices while adapting them intelligently to local realities, that we can hope to create urban spaces where the mobility and autonomy of blind or visually disabled people are fully considered, while promoting the fluid and respectful cohabitation of all road users.

The study's main contributions include providing a deeper understanding of the challenges faced by people with visual

disabilities in shared street environments, particularly within heritage contexts in Canada. It also explores potential universal design solutions that could enhance accessibility while preserving the cultural and historical integrity of such sites. The research highlights the importance of co-design with experts from various fields, offering a collaborative approach to solving accessibility issues. Furthermore, it brings to light the specific needs of visually impaired individuals in urban planning, contributing to the broader discourse on inclusive design.

However, the study also has limitations. These include a potentially narrow focus on Canadian contexts, which might limit the applicability of the findings in other regions with different cultural, legal, and environmental conditions. The reliance on a relatively small number of experts ($n = 7$) for the validation phase might also restrict the diversity of perspectives included in the analysis. Additionally, the study's conclusions are drawn from a combination of literature review and expert opinion, which may not fully capture the lived experiences of people with visual disabilities. Specifically, only one person with visual impairment and one caregiver of a visually impaired person were consulted, which may not adequately represent the broader spectrum of experiences and needs within the visually disabled community. Future research could benefit from more extensive field studies and direct engagement with a larger and more diverse group of individuals with visual disabilities to validate and expand upon these findings.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The study was approved by the sectorial ethics committee on research in rehabilitation and social integration of the Centre Intégré Universitaire de Santé et de Services Sociaux de la Capitale-Nationale (#2022–2422) and every participant signed a consent form.

Author contributions

ML: Conceptualization, Formal Analysis, Investigation, Methodology, Validation, Writing – original draft. EM: Methodology, Supervision, Validation, Writing – review & editing. AR-R: Writing – review & editing. IF: Writing – review & editing. SM: Writing – review & editing. FR: Writing – review & editing.

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Conflict of interest

SM was employed by Le ministère de la Culture et des Communications.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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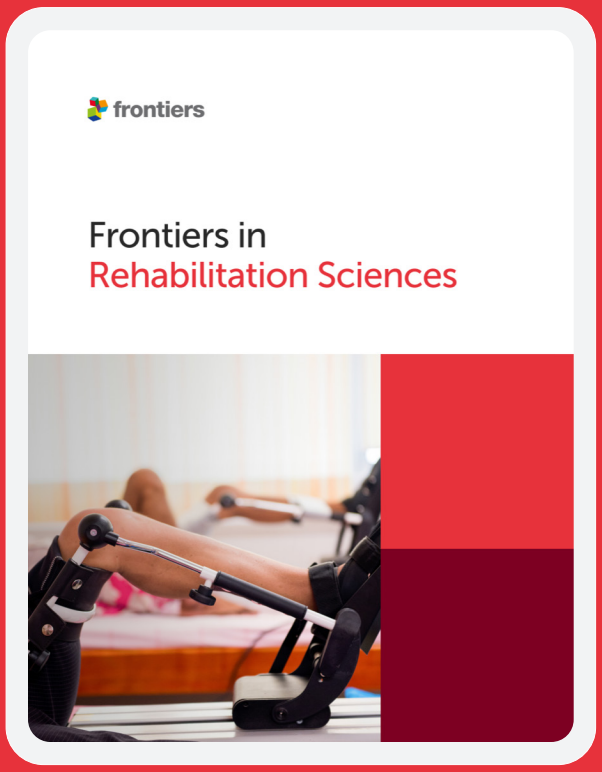

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